GEOLOGY OF THE ARCHEAN ASHUANIPI COMPLEX, WESTERN LABRADOR

D.T. James

Report 97-2

St. John's, Newfoundland
1997

GOVERNMENT OF
NEWFOUNDLAND AND LABRADOR
Department of Mines and Energy
Geological Survey

COVER

Granulate-facies granitoid migmatite (Unit 4) containing sheets of weakly deformed leucogranite, Ashuanipi Complex, western Labrador (photo DJ-91-6250).

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ABSTRACT

The Ashuanipi Complex, southeast Superior Province, is an Archean high-grade gneiss terrane. In western Labrador, it principally consists of metasedimentary migmatite, tonalitic to granitic orthogneisses, voluminous plutons of monzogranite to granodiorite (diatexite), and late syn- to postmetamorphic plutons and smaller intrusions of biotite ±muscovite granite. The metasedimentary rocks, inferred to be derived from greywacke, contain coexisting orthopyroxene, garnet and biotite, and one or two phases of metamorphic leucosome. Minor mafic gneiss, possibly derived from mafic volcanic rocks, is interlayered with the metasedimentary migmatite. Intrusions of tonalite, granodiorite, granite, and olivine pyroxenite dykes (and layered sills?) were emplaced into the supracrustal rocks prior to ca. 2685- to 2650-Ma high-grade metamorphism and attendant deformation. The orthogneisses also contain metamorphic orthopyroxene and, with the exception of the olivine pyroxenite rocks, are migmatitic.

The metasedimentary rocks and orthogneisses are intruded by plutons of variably deformed orthopyroxene ± garnet-bearing diatexite. The fact that the diatexite contains xenoliths of the older units having deformed, orthopyroxene-bearing metamorphic leucosome demonstrates that they postdate the onset of granulite-facies metamorphism and the formation of west-northwest- to northwest-trending early syn-metamorphic structures in host gneisses. Thus, their emplacement is inferred to be syn- to late syn-metamorphic. The diatexite and older units are deformed by late syn-metamorphic superposed folds producing a regional-scale structural pattern of culminations and depressions. The culminations are cored by the diatexite and the depressions by pre-diatexite units.

High-grade rocks in the southern part of the study area are intruded by the Walsh River pluton, a composite intrusion consisting of biotite±muscovite granite. Rocks that make up the intrusion are variably foliated and recrystallized. Emplacement is considered to be late syn- to posttectonic with respect to the high-grade metamorphism and deformation. In addition, minor intrusions and dykes of late syn- to posttectonic biotite-bearing granite and pegmatite occur throughout the area.

Northeast-striking faults, inferred to be steeply southeast-dipping Grenvillian structures having a reverse kinematic sense, deform Ashuanipi Complex rocks in the southern part of the study area. The most northern fault represents the Grenville Front. The faults are one component of a bipartite fold-and-thrust belt (Gagnon terrane) that includes a system of thin-skinned structures, which are mainly confined to a cover sequence (Paleoproterozoic Knob Lake Group), and a system of steeply dipping reverse faults that deform the cover, the basement (Ashuanipi Complex), and the thin-skinned structures. A foliation, of inferred Grenvillian age, is developed locally in the Walsh River pluton. Greenschist-facies retrogression of Ashuanipi Complex rocks south of the Grenville Front is presumed to be a Grenvillian feature.

Background levels of gold and gold-sympathetic elements revealed from lake-sediment geochemical surveys in the Ashuanipi Complex are anomalous and higher than might normally be expected from an Archean high-grade gneiss terrane. The geochemical studies, and the documented occurrence of gold in Ashuanipi Complex rocks northwest of Schefferville, Quebec, suggest the Ashuanipi Complex has some potential for Archean mesothermal gold mineralization.

INTRODUCTION

LOCATION AND ACCESS

The study area is located in western Labrador, north and west of Labrador City (Figure 1). It takes in parts of the Shabogamo Lake (NTS 23G) and Lac Opocopa (NTS 23B) map areas, including parts of NTS map areas 23G/2, G/3, G/7, G/10, G/11, G/13, G/14 and G/15, and 23B/14 (Figure 2; *see also* maps 97-03 and 97-04).

The interior of the study area can only be reached by helicopter or by float-equipped aircraft. Access to the eastern margins is made by boat from Esker, located at the termination of the Brinco Road at Menihek Lakes (Figure 1), and by passage to Sawbill Lake through Steers and Shabogamo lakes (*see* maps 97-03 and 97-04), accessed from the Trans-Labrador Highway, 35 km east of Labrador City. The southern part of the study area is reached by boat through Huguette Lake and Lac Virot, located 13 km southwest of Labrador City.

PHYSIOGRAPHY AND EXPOSURE

The northern part of the study area (*see* Map 97-03) is characterized by an undulating and locally rugged topography having an average elevation of 650 m above sea level (asl). The highest elevation of 875 m asl is at a point near the southwest corner of NTS map area 23G/10 on the Newfoundland–Quebec border. Another prominent landmark is a high (825 m asl), broad (4 km wide) hill located 5 km southeast of Milner Lake. This topography is in marked contrast to the low (550 m asl) and flat areas underlain by Paleoproterozoic Knob Lake Group rocks to the east.

The valleys in this part of the study area are heavily forested and commonly contain long, narrow lakes or river systems that drain the area to the east, into the Menihek Lakes. Often, the valleys are poorly exposed, and are sometimes underlain by supracrustal gneisses and orthogneisses (Units 1 to 5). In contrast, the hills are barren of trees above ca. 700 m asl, and have excellent outcrop exposures, and are mainly underlain by diatexite (Unit 6).

The topography of the southern part of the study area (*see* Map 97-04) is significantly less rugged than it is to the north. It is characterized by a few low hills and broad, flat valleys commonly containing extensive systems of bogs and shallow lakes. The average elevation is approximately 650 m asl. The maximum elevation of 750 m asl occurs in the western part of NTS map area 23G/3. The minimum elevation of 570 m asl occurs at Lac Virot in NTS map area 23B/14. The area is drained to the southeast by the Walsh and Ironstone river systems. The area is poorly exposed, forested, and is mainly underlain by the Walsh River pluton. This topography is in contrast to the prominent ridges and hills found to the southeast, and underlain by the Paleoproterozoic Wishart (quartzite) and Sokoman (ironstone) formations of the Knob Lake Group.

OBJECTIVES

Prior to 1991, the southeastern Ashuanipi Complex had been mapped only at a reconnaissance scale. Consequently, the lack of detailed field observations undermined the utility of existing geological maps in relation to current exploration needs. In view of the results from regional geochemical surveys, which suggest the Ashuanipi Complex has potential for gold mineralization, and the discovery of gold in the Ashuanipi Complex northwest of Schefferville, Quebec (Lapointe, 1986, 1989; Lapointe and Chown, 1993), it became necessary to upgrade the geological map for this part of the Ashuanipi Complex.

The study area was mapped at a scale of 1:100 000. The results (Maps 97-03 and 97-04) provide a regional geological context for gold reconnaissance investigation of the Ashuanipi Complex carried out jointly with the Geological Survey of Canada and the Newfoundland Department of Mines prior to the 1980s' lake-sediment geochemistry programs. This study also contributes to the overall understanding of structural, metamorphic and intrusive relations within the Ashuanipi Complex.

PREVIOUS INVESTIGATIONS

Parts of the study area have been previously mapped at a scale of 1":4 miles by Stevenson (1964) and Fahrig (1967; Figure 3). Cursory examinations of the eastern margin of the Ashuanipi Complex have also been made in the course of mapping the Paleoproterozoic Knob Lake Group to the east and south (e.g., Rivers 1985a to c; Brown, 1988; Brown *et al.*, 1991). Detailed mapping and an upgraded 1:100 000-scale compilation map of the Knob Lake Group and contiguous Ashuanipi Complex in the Labrador City area by van Gool (1992), has outlined areas of Ashuanipi Complex rocks that occur as tectonic slices within a Grenvillian fold-and-thrust belt (Gagnon terrane). Occurrences of Ashuanipi Complex rocks in the highly strained parts of the Gagnon terrane were not examined.

The study area has been surveyed by a regional, lake-sediment geochemistry program (Geological Survey of

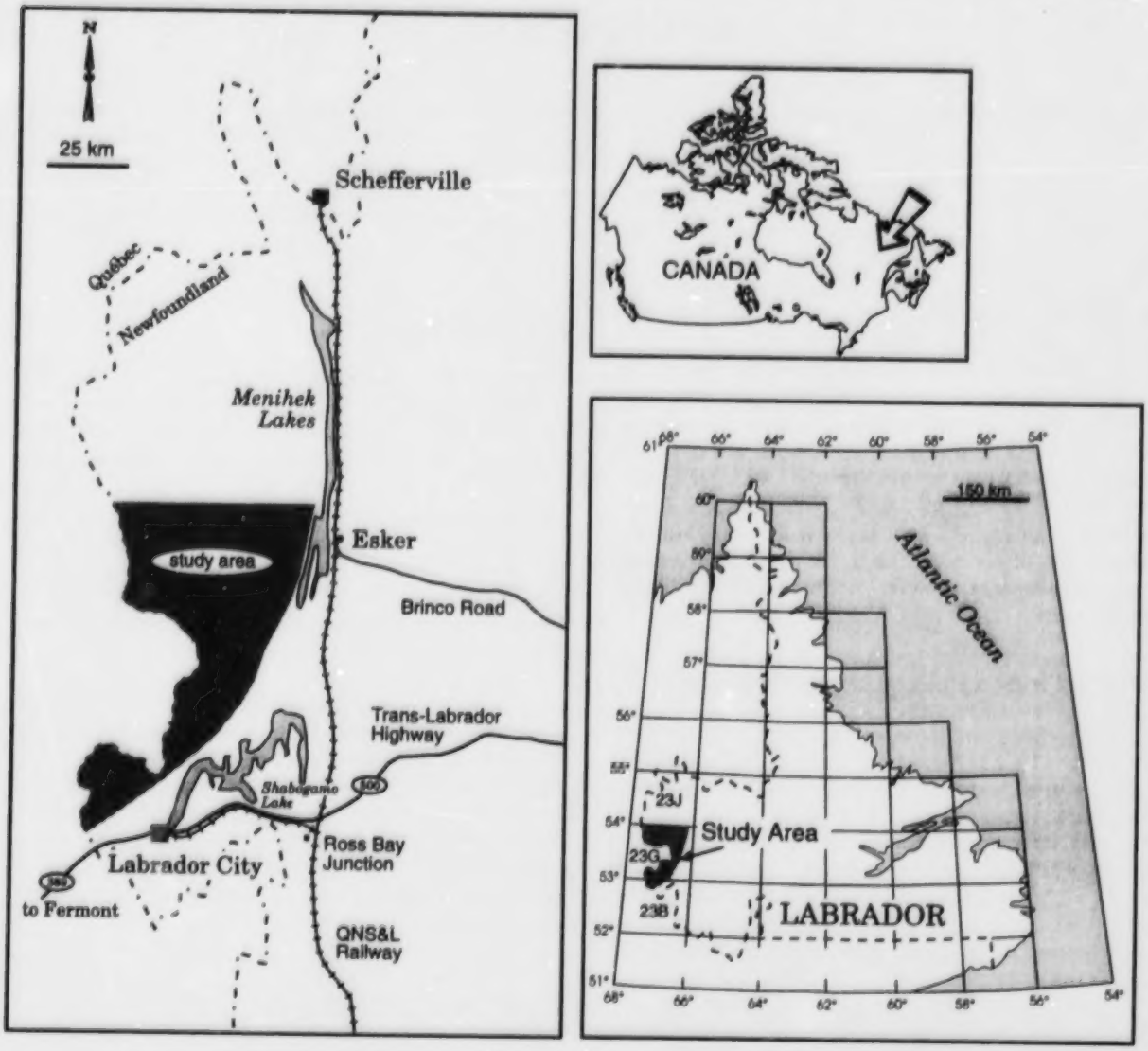

Figure 1. *Index maps showing the location of the study area (stippled pattern).*

Canada, 1983a,b). Follow-up studies by Thomas and Butler (1987), Butler (1987), McConnell *et al.* (1987) and McConnell and Newman (1988) concentrated on locating the source of geochemical anomalies discovered during the lake-sediment survey.

To the north of the study area, in NTS map area 23J, the Ashuanipi Complex has been mapped at 1:125 000-scale by Percival (1987, 1989) and Percival and Girard (1988). Prior to Percival's work, the Ashuanipi Complex in that area had been mapped at a scale of 1":4 miles by Frarey (1961) and Stevenson (1963), and farther north, in NTS map area 23O, by Baragar (1967).

PRESENT INVESTIGATION

During the three-month field season of 1991, mapping concentrated on areas north of 53°20'N, in NTS map area 23G. This represents approximately 85 percent of the study area. Mapping was carried out by two traversing teams and included helicopter- and boat-supported ground traverses and helicopter landings on isolated outcrops. Fieldwork was mainly conducted from a base camp located on the Brinco road, 6 km south of Esker (Figure 1).

The southern part of the study area, including NTS map areas 23G/2, G/3 and 23B/14, was mapped over a two-week

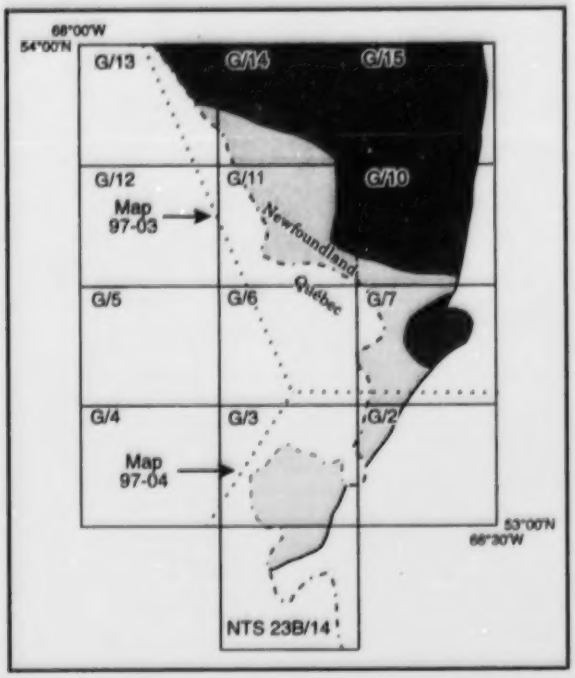

Figure 2. *Detailed index and reliability map for the study area (parts of NTS areas 23G and 23B). Areas mapped using a combination of ground traverses and helicopter landings on isolated outcrops are shown in the dark stipple pattern. Areas mapped using mainly helicopter landings and a few ground traverses are shown in the light stipple pattern.*

period in June of 1992. Mapping was conducted entirely by making helicopter landings on isolated outcrops. The 1992 field season was based in Labrador City. Preliminary results of the mapping have been presented in James and Stephenson (1992), James and Mahoney (1993), and James (1993).

REGIONAL SETTING

The Ashuanipi Complex is a 90 000 km^2 high-grade Archean gneiss domain that comprises the southeastern part of the Superior Province (Figure 4). On the basis of reconnaissance mapping of this domain, which was conducted as part of a more detailed investigation of the Paleoproterozoic rocks of the Labrador Trough in western Labrador in the 1950s and 1960s, the Archean metamorphic and intrusive rocks of the Superior Province were collectively named the Ashuanipi Group by Frarey (1961). Subsequently, the rocks were renamed the Ashuanipi Complex by Fahrig (1967). Card and Ciesielski (1986) elevated the Ashuanipi Complex to subprovince status, although the term Ashuanipi Complex is still in widespread use (e.g., Percival, 1987, 1989, 1990, 1991a; Percival and Girard, 1988; Machado and Chevé, 1991).

The Ashuanipi Complex is composed of high-grade supracrustal rocks and orthogneisses, orthopyroxene-bearing granitoid rocks, and minor postmetamorphic tonalite, granodiorite, granite and rare syenite plutons (Eade, 1966; Percival, 1987, 1989, 1990, 1991a; Percival and Girard, 1988; Machado and Chevé, 1991). The supracrustal rocks are inferred to be derived mainly from greywacke but there are also minor amounts of presumed metamorphosed mafic volcanic rocks. Most of the complex is composed of granulite-facies rocks, although there are zones of retrogression to amphibolite facies (Herd, 1978).

A sequence of events in the eastern part of the Ashuanipi Complex established by conventional and ion-probe U–Pb geochronology (Table 1) suggests the following history:

1) > 2700 Ma. Sedimentation accompanied by minor mafic volcanism; deposition of the sedimentary rocks was completed by approximately 2.7 Ga (Mortensen and Percival, 1987; Chevé and Brouillette, 1991; Percival *et al.*, 1991).
2) 2700 to 2680 Ma. Intrusion of tonalite plutons and sills, and of granodiorite, diorite and minor gabbro into the supracrustal rocks (Chevé and Brouillette, 1991; Machado and Chevé, 1991; Percival, 1991a; Percival *et al.*, 1991).
3) 2685 to 2650 Ma. High-grade metamorphism, deformation and intrusion of voluminous, syn- to late syn-metamorphic orthopyroxene-bearing granodiorite (diatexite) plutons, and intrusions of granodiorite and syenite (Mortensen and Percival, 1987; Percival *et al.*, 1988, 1991; Chevé and Brouillette, 1991).
4) ca. 2666 Ma. Initiation of cooling following peak metamorphism; late syn- to postmetamorphic ages are based on U–Pb monazite data (Mortensen and Percival, 1987; Percival *et al.*, 1988, 1991), which suggest rapid cooling following the metamorphic peak (Percival, 1990).
5) ca. 2650 Ma. Intrusion of posttectonic pegmatites and leucogranite (Mortensen and Percival, 1987; Percival *et al.*, 1991).
6) 2650 to 2600 Ma. Postmetamorphic thermal events; these are dated by growth of new zircon in a diatexite (Mortensen and Percival, 1987), and monazite in pre-2650 Ma units (Chevé and Brouillette, 1991; Machado and Chevé, 1991).
7) 2625 Ma. Intrusion of nepheline syenite bodies (Machado and Chevé, 1991).

To the west, the Ashuanipi Complex passes into the lower-grade Opinaca River and La Grande River subprovinces, which mainly consist of metasedimentary rocks, and metamorphosed volcanic and plutonic rocks, respectively (Figure 4; Card and Ciesielski, 1986). The boundary between the Ashuanipi Complex, and these two subprovinces is a grad-

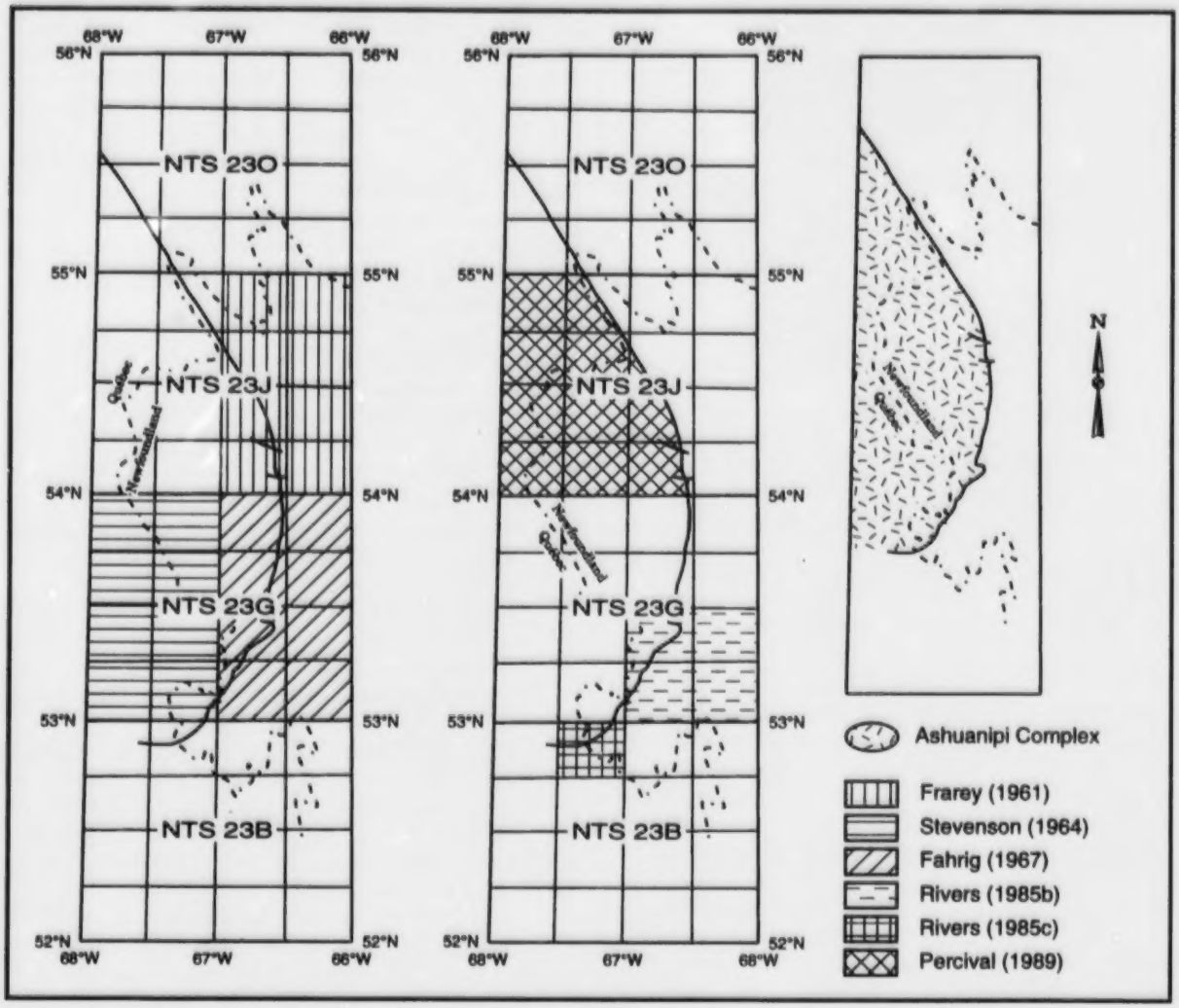

Figure 3. *Field mapping coverage of the Ashuanipi Complex in western Labrador. The map on the left shows areas mapped by Frarey (1961), Stevenson (1964) and Fahrig (1967). The centre map shows areas mapped by River (1985b, c) and Percival (1989). The generalized map on the right shows distribution of the Ashuanipi Complex in western Labrador.*

ational amphibolite to granulite transition zone having prograde and retrograde components (Percival, 1990). To the north, the Ashuanipi Complex is bound by the Bienville Subprovince (Card and Ciesielski, 1986), which is mainly composed of orthogneiss, but has a minor amount of supracrustal rocks (Ciesielski, 1991).

On a regional scale, Mortensen and Percival (1987) have recognized a similarity in rock types, structural styles and orientation, and a synchroneity in intrusive and metamorphic events between the Ashuanipi Complex and the Quetico Subprovince of northwestern Ontario. On this basis, Percival (1990) and Percival *et al.* (1991) infer the Ashuanipi Complex to be a continuation of the major metasedimentary subprovinces that occur in the central and western parts of the Superior Province. These subprovinces, including the Ashuanipi, Opinaca River, Nemiscau River, Opatica and Quetico (Figure 4), collectively make up a metasedimentary-dominated belt that is more than 2100 km long (although stratigraphic and structural linkages between many of these subprovinces remain to be established). Percival and Williams (1989) and Williams (1990) proposed that metasedimentary subprovinces in the Superior Province developed as sedimentary prisms between accreting volcanic arcs.

The Ashuanipi Complex is unconformably overlain by the Paleoproterozoic Knob Lake Group (Frarey and Duffell, 1964) of the Labrador Trough (*see* Map 97-03). Along the southeastern and southern boundary of the Ashuanipi Complex, the Ashuanipi Complex–Knob Lake Group contact is a

Grenvillian reverse fault (*see* Map 97-04), which carries Knob Lake Group rocks over the Ashuanipi Complex (*see* Rivers, 1983, 1985a and c; van Gool, 1992; van Gool *et al.*, 1987, 1988; Brown, 1988; Brown *et al.*, 1991). Locally, Grenvillian faulting also involves Ashuanipi Complex rocks (van Gool, 1992).

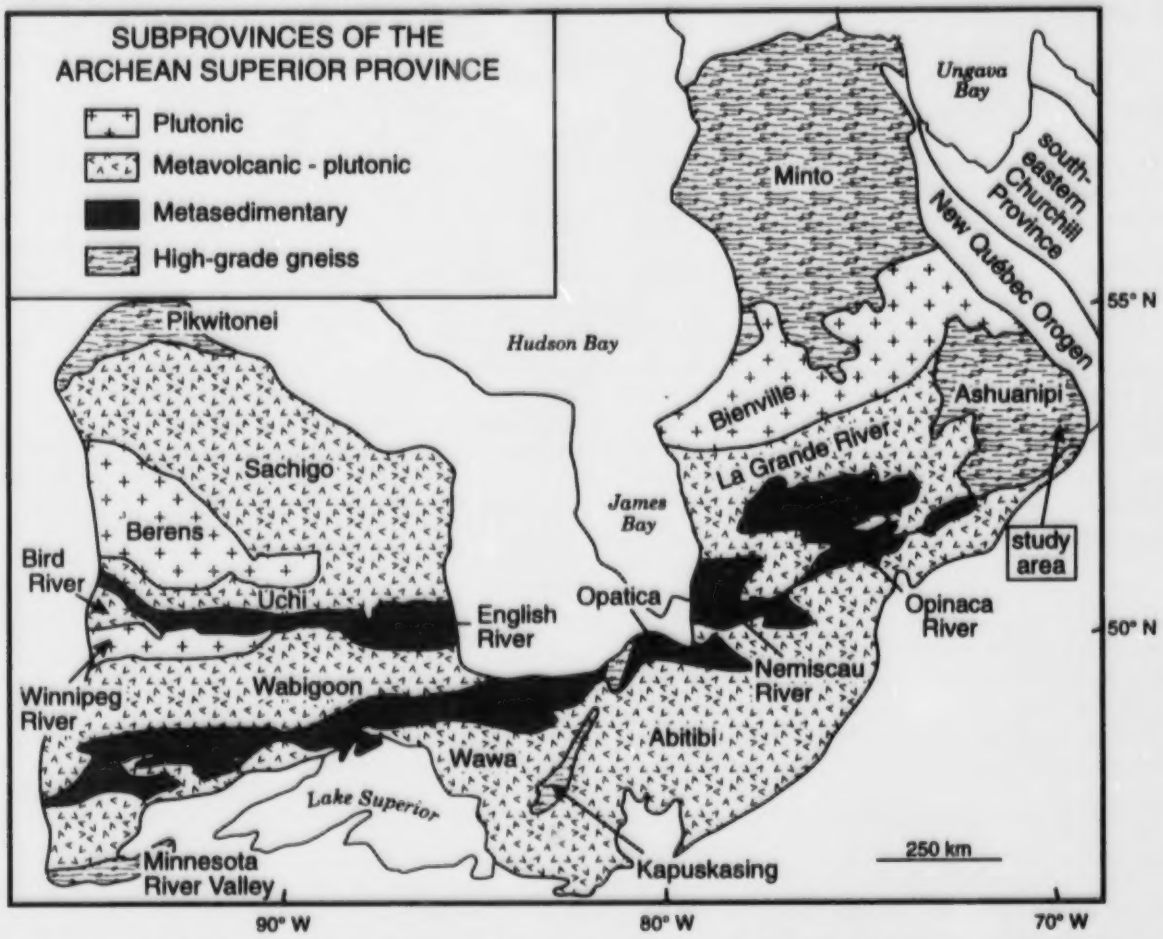

Figure 4. *Map of the Superior Province showing the principal tectonostratigraphic subdivisions (modified after Card and Ciesielski, 1986).*

Table 1. Summary of geochronological data from the Ashuanipi Complex

Age	System	Major Unit / Event	Interpretation	Ref.
3.4 to 2.7 Ga	U – Pb zir	metasedimentary rocks	ages of detrital zircons from metasedimentary rocks; 2.7 Ga is the maximum depositional age of the metasedimentary rocks	5,7
2698 ± 3 Ma	U – Pb zir	granodiorite	age of emplacement of granodiorite	2
2697 ± 3 Ma	U – Pb zir	two pyroxene tonalite	age of emplacement of tonalite	2
2698 to 2692 Ma	U – Pb	tonalite and granodiorite	age of emplacement of tonalite and granodiorite intrusions	1
2692 ± 9 Ma	U – Pb zir	tonalite (Desliens Igneous Suite)	age of emplacement of tonalite and related intrusions	3,5
2685 ± 3 Ma	U – Pb zir	tonalite	age of emplacement of tonalite	7

.....continued on next page

Table 1. Continued

Age	System	Major Unit / Event	Interpretation	Ref.
2682 $^{+5}_{-3}$ Ma	U – Pb zir	garnet-absent diatexite	age of emplacement of diatexite	4,5,6,7
2680 ± 4 Ma	U – Pb zir	tonalite	age of emplacement of tonalite	7
2670 Ma	U – Pb zir	syenite	age of emplacement of syenite	7
2669 Ma	U – Pb zir	granodiorite	age of emplacement of granodiorite	7
2668 Ma	U – Pb zir	leucosome	age of formation of metamorphic leucosome	7
2668 ± 1 Ma	U – Pb zir	garnet-absent diatexite	age of emplacement of diatexite	4,5,7
2662 ± 3 Ma	U – Pb zir	garnet-bearing diatexite	age of emplacement of diatexite	4
2666 to 2662 Ma	U – Pb mz	diatexite	age of formation of monazite in diatexite	7
2654 ± 5 Ma	U – Pb mz	pegmatite	age of emplacement of a massive pegmatite that crosscuts WNW structural fabric in host rocks	3,4
2653 ± 3 Ma	U – Pb zir	homogeneous diatexite	age of emplacement of homogeneous diatexite	2
2670 to 2650 Ma	U – Pb	—	high-grade metamorphism and attendant deformation based on zircon and monazite ages	1
2650 Ma	U – Pb mz	leucogranite	age of emplacement of leucogranite	6
2645 ± 6 Ma	U – Pb mz	tonalitic leucosome	age of formation of metamorphic leucosome	2
2642 ± 3 Ma	U – Pb zir	retrograded diatexite	maximum age of a thermal event marked by growth of zircon in diatexite	3
2671 to 2639 Ma	U – Pb mz	pegmatites	ages of emplacement of late pegmatites	7
2650 to 2639 Ma	U – Pb	—	cooling from the metamorphic peak and retrogression	1
2650 to 2632 Ma	U – Pb mz	tonalite	age of formation of monazite in tonalite	7
2625 ± 3 Ma	U – Pb bd	syenite	age of emplacement of late syenite intrusions	2
2619 ± 6 Ma	U – Pb mz	granodiorite	thermal event marked by growth of monazite in ca. 2698 Ma granodiorite	2
2604 Ma	U – Pb mz	syenite	thermal event marked by growth of monazite in a ca. 2670 Ma syenite	7

Key: zir – zircon, mz – monazite, bd – baddeleyite.
References: 1 – Chevé and Brouillette (1991), 2 – Machado and Chevé (1991), 3 – Mortensen and Percival (1987), 4 – Percival (1991a), 5 – Percival *et al.* (1988), 6 – Percival *et al.* (1991), 7 – Percival *et al.* (1992)

LITHOLOGY

METASEDIMENTARY MIGMATITE (UNIT 1)

On the basis of intrusive crosscutting relationships observed in the field, the metasedimentary migmatite (Unit 1) is interpreted to be the oldest unit in the study area (Figure 5; *see* also maps 97-03 and 97-04). The unit includes rocks consisting of a grey-, brown- or rusty-weathering biotite-rich paleosome (Plate 1) and white-weathering leucosome. The paleosome:leucosome ratio is variable throughout the unit. The unit is divided into three subunits. Subunit 1a contains paleosome having abundant garnet and local sillimanite; subunit 1b contains paleosome having only local garnet, and subunit 1c is a heterogeneous division consisting of metasedimentary migmatite and metatonalite intrusions, which can be correlated with Unit 3 (*see* page 9).

In the three subunits, the paleosome is fine grained and has a granoblastic texture defined by quartz, andesine plagioclase and K-feldspar. The K-feldspar commonly occurs as medium- to coarse-grained spongy-textured porphyroblasts containing quartz and biotite inclusions; a very fine-grained, wormy intergrowth of quartz in K-feldspar is common. Biotite is fine to medium grained and makes up less than 15 percent of the paleosome. A fine-grained, lamellar intergrowth of quartz in biotite is common, especially where biotite grains are in contact with orthopyroxene. Garnet forms fine- to coarse-grained porphyroblasts and poikiloblasts. Sillimanite occurs as fine- to medium-grained acicular grains. The paleosome contains accessory magnetite, pyrite and apatite.

Orthopyroxene is ubiquitous except in sillimanite-bearing rocks. It occurs in the paleosome as fine, equant grains, and as medium- to coarse-grained porphyroblasts containing a variable amount of plagioclase and quartz inclusions. Garnet inclusions in orthopyroxene poikiloblasts are rare. Some of the coarse-grained orthopyroxene poikiloblasts have elliptical to very irregular-shaped outlines, and consist of more than 50 percent inclusions. Several of the orthopyroxene-bearing rocks contain a minor amount of fine-grained, light-yellow or green, pseudomorphed grains (pinite?) that may have been cordierite. On the basis of texture, biotite and orthopyroxene appear to be stable, although in rare cases, biotite grains appear to overgrow (i.e., rim) orthopyroxene. In most rocks, orthopyroxene is variably pseudomorphed by bastite and minor amounts of carbonate.

The metasedimentary migmatite commonly contains two phases of leucosome, which are distinguished on the basis of crosscutting relationships. The amount of leucosome is generally greater than 30 percent and locally exceeds 60 percent. Both phases are white-weathering and contain K-feldspar, or locally microcline, and minor amounts of biotite and commonly orthopyroxene. The older of the two phases forms thin (1 to 10 cm) and closely spaced, subparallel to anastomosing layers. The younger phase is discordant to the first, and forms layers that locally exceed a thickness of one metre. Locally, the younger phase is observed to postdate folds of the older phase.

Unit 1 also includes several occurrences, too small to be recorded on a map, of pelitic gneiss, containing abundant amounts of biotite and accessory spinel, and white-weathering calc-silicate gneiss. The calc-silicate gneiss consists of plagioclase, diopside, quartz and biotite, and is inferred to be derived from an impure siliceous carbonate sediment. Local, lens-shaped, rusty-weathering pods (<1 m long), which consist of abundant biotite, garnet and minor amounts of pyrite, are interpreted to be the highly dismembered relicts of silicate-sulphide facies iron formation.

The metasedimentary migmatite commonly contains thin (<1 m) mafic dykes, which are metamorphosed and deformed to the same extent as the host rocks (Plate 2). These relationships demonstrate that these dykes predate the granulite-facies metamorphism. The dykes have granoblastic textures and consist of two pyroxenes, hornblende and plagioclase.

Unit 1 is inferred to be derived from a sedimentary sequence that consisted mainly of psammitic to semipelitic rocks. The rarity of Al-rich minerals suggests that the sedimentary precursors were probably not aluminous pelitic rocks. The abundance of garnet in subunit 1a, as compared to subunit 1b, suggests that subunit 1a was derived from slightly more aluminous (i.e., pelitic) and iron-rich rocks than subunit 1b.

MAFIC GNEISS (UNIT 2)

Local occurrences of mafic gneiss interlayered with the Unit 1 rocks define Unit 2. The contacts between the two units are sharp, and are inferred to be stratigraphic. The mafic gneiss is black- and white-weathering, fine grained and finely foliated. Typically, the rocks display a well-developed gneissosity defined by alternating mafic and feldspathic layers that are commonly less than 5 cm thick. They may also contain up to 20 percent, thin (<10 cm) layers of white, tonalitic leucosome.

The paleosome is a fine- to medium-grained rock having a granoblastic texture defined by grains of clinopyroxene,

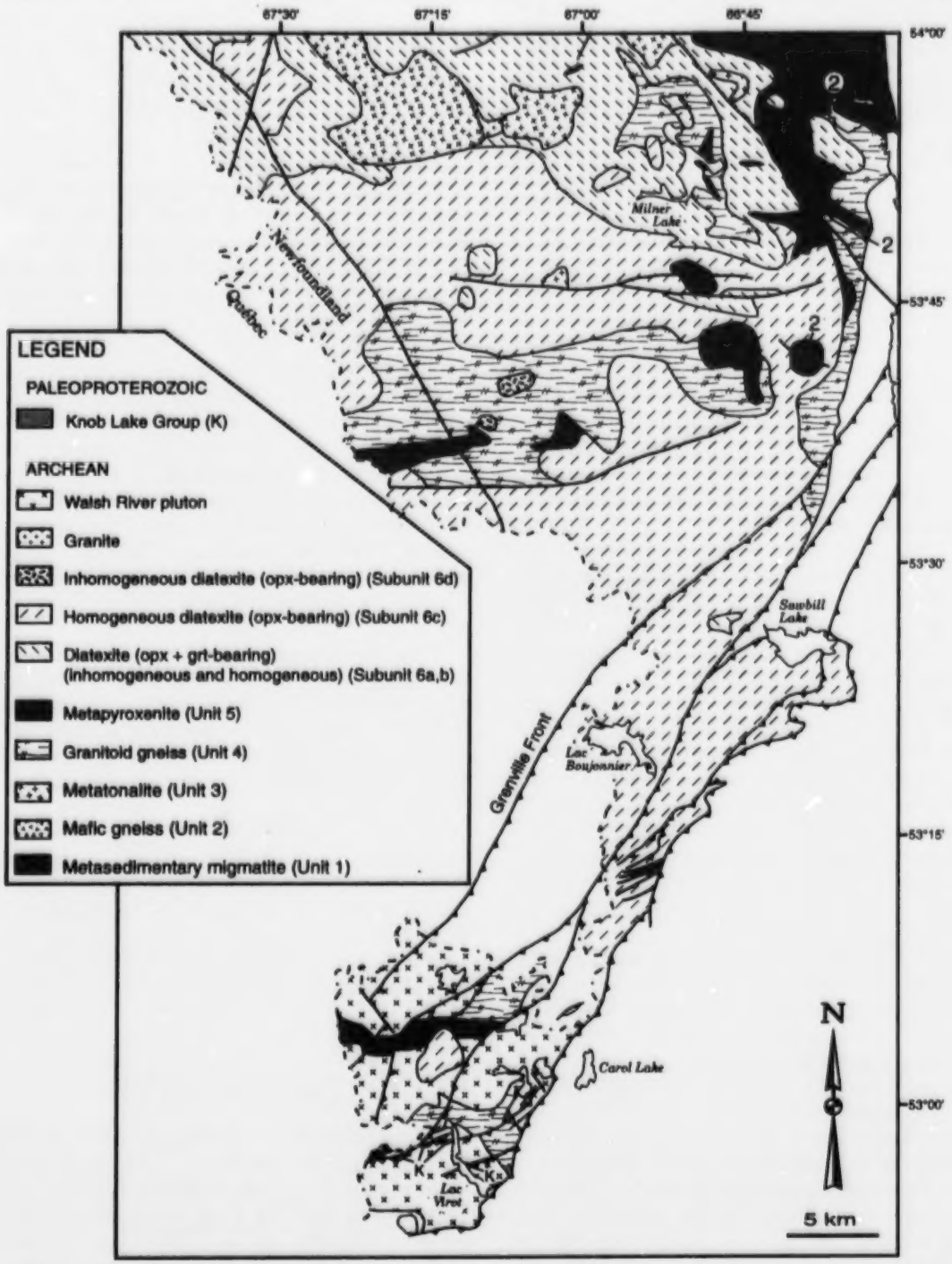

Figure 5. *Generalized geological map of the study area. Unit numbers used in the text and shown on maps 97-03 and 97-04 are listed in parentheses. Metasedimentary migmatite (Unit 1), mafic gneiss (Unit 2), metatonalite (Unit 3), granitoid gneiss (Unit 4), meta-pyroxenite (Unit 5), homogeneous and inhomogeneous garnet and orthopyroxene-bearing diatexite (subunits 6a, and b), homogeneous orthopyroxene-bearing diatexite (subunit 6c), inhomogeneous orthopyroxene-bearing diatexite (subunit 6d), granite (Unit 7), and Walsh River pluton (Unit 8). Areas underlain by Paleoproterozoic Knob Lake Group rocks in the Lac Virot area are shown by the horizontal-stripe pattern and indicated by the letter K.*

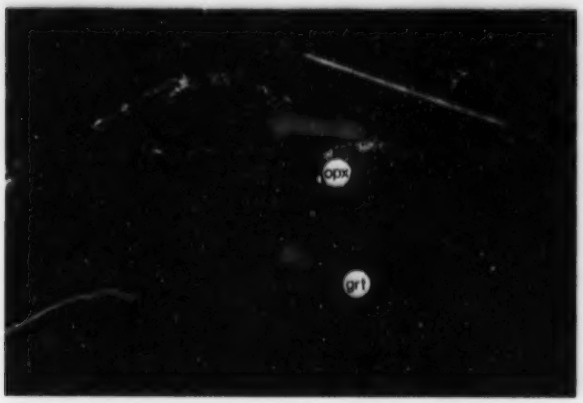

Plate 1. *Metasedimentary migmatite (Unit 1) containing coarse-grained porphyroblasts of garnet (grt) and orthopyroxene (opx).*

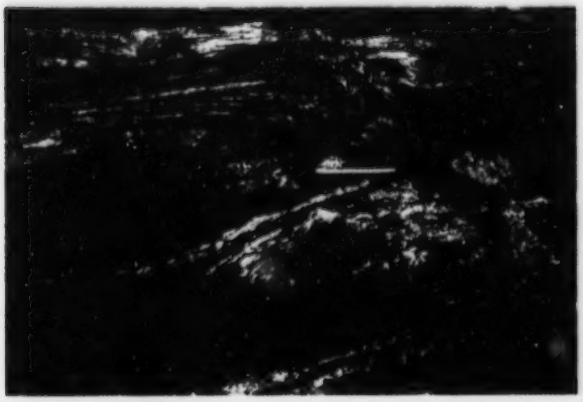

Plate 2. *Metasedimentary migmatite (Unit 1) containing the dismembered relicts of a pre-metamorphic mafic dyke.*

orthopyroxene, hornblende, and andesine plagioclase. The mafic minerals make up approximately 50 percent of the paleosome. Pyroxene is generally more abundant than hornblende, although the percentages of the mafic minerals are slightly varied. The rocks also contain minor amounts of quartz, and accessory magnetite, apatite and pyrite.

The interpretation of hornblende and pyroxene textures in the paleosome is equivocal. Most contacts between the two minerals are straight (granoblastic) and the grains appear to be in textural equilibrium. Less commonly, some of the hornblende grains appear to overgrow orthopyroxene. The two textural variations of hornblende may occur in the same rock and suggest that rocks locally contain two generations of hornblende. These younger hornblende grains may be related to hornblende growth around orthopyroxene during rehydration of the rocks following the thermal peak of the granulite-facies metamorphism.

The leucosome is fine to medium grained and is mainly composed of plagioclase, quartz, and minor amounts of biotite. It generally forms thin (<10 cm) and subparallel layers throughout the rocks.

The mafic gneiss could be derived from either mafic volcanic rocks or from pre-metamorphic gabbro intrusions emplaced into Unit 1 sedimentary rocks. There are insufficient data to make a definitive conclusion about the protolith of the mafic gneiss, although based on its association with the metasedimentary rocks, a supracrustal protolith is favoured. In support of this model, it could be argued that the layered structure of this unit may be an accentuation of original compositional (volcanic) layering, although other primary volcanic structures could not be identified.

METATONALITE (UNIT 3)

Plutons mainly composed of metamorphosed tonalite and lesser amounts of metamorphosed quartz diorite, diorite and gabbro are defined as Unit 3. Contact relations between the different rock types that make up the unit have not been established. Contacts between the metatonalite and the metasedimentary migmatite are commonly gradational, and are marked by a zone of metatonalite containing abundant enclaves of metasedimentary gneiss. These contacts are placed where the amount of metatonalite exceeds that of metasedimentary rocks. The metatonalite also occurs as dykes and sheets contained within the metasedimentary migmatite (subunit 1c); however, they are too small to be recorded on the map.

The rocks of this unit are foliated and commonly gneissic (Plates 3 and 4). The gneissosity is defined by layers containing different proportions of plagioclase and mafic minerals, and interlayered with tonalitic leucosome. In a few outcrops, thin (<20 cm) mafic- and plagioclase-rich layers form a very regular and continuous layering that may be a relict of an original igneous cumulate structure (Plate 5). Rare tonalite dykes appear to contain relict chill margins (Plate 6).

The rocks are black- and white-weathering. They are fine to medium grained, and consist of plagioclase (oligoclase to andesine), quartz and variable amounts of orthopyroxene, clinopyroxene and approximately 5 percent biotite. Clinopyroxene is generally less abundant than orthopyroxene, and absent in some rocks. Locally, minor amounts of K-feldspar or perthitic microcline are present. The rocks contain accessory magnetite, apatite and local epidote.

The rocks mainly have a fine- to medium-grained granoblastic texture defined by plagioclase, quartz and pyroxene. Locally, rocks are coarse grained and contain coarse-grained blocky, prismatic orthopyroxene containing abundant inclusions of stubby, prismatic plagioclase grains (<0.7 mm). The presence of texturally similar orthopyroxene in the

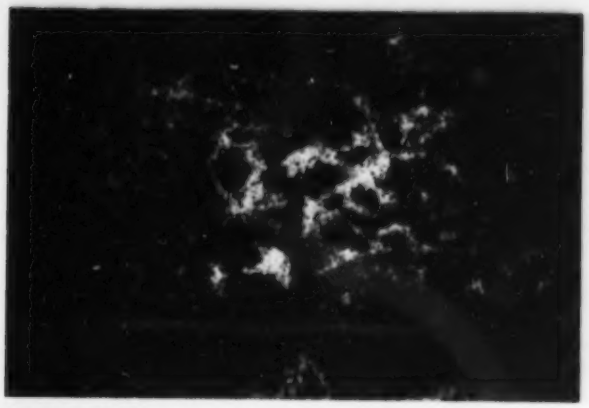

Plate 3. *Metatonalite (Unit 3) containing coarse-grained (1 to 2 cm) orthopyroxene poikiloblasts (grey spots). The poikiloblasts contain inclusions of fine-grained, granoblastic plagioclase and quartz.*

Plate 4. *Typical field aspects of migmatitic metatonalite (Unit 3) containing orthopyroxene and hornblende.*

diatexite (subunits 6a to d) suggests a metamorphic origin for the blocky orthopyroxene in the metatonalite.

Some of the rocks have a poikiloblastic texture defined by medium- to coarse-grained, elliptical to irregular-shaped orthopyroxene poikiloblasts (Plate 3). The poikiloblasts contain up to 50 percent inclusions of granoblastic plagioclase and quartz that are texturally identical to the plagioclase and quartz in the matrix. These poikiloblasts have been interpreted to be relict igneous oikocrysts by Percival (1991a). However, these poikiloblasts have an identical texture to some of the orthopyroxene poikiloblasts in the metasedimentary migmatite unit, which suggests they are more likely metamorphic grains. The textural similarities between the quartz and feldspar grains in the matrix, and those in the poikiloblasts, are consistent with the interpretation of the orthopyroxene being metamorphic.

The orthopyroxene is variably retrogressed. Locally, grains are overprinted by minor amounts of hornblende and

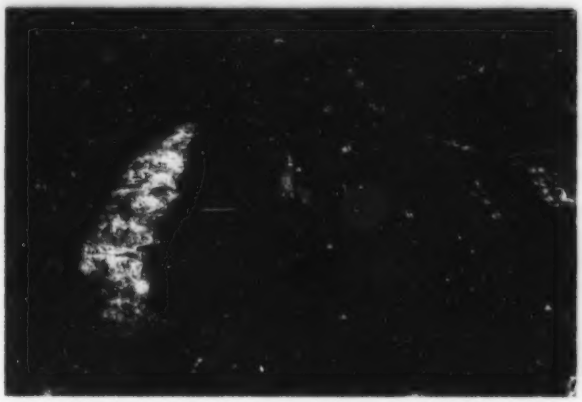

Plate 5. *Layering in metadiorite (Unit 3). This outcrop contains two types of layering, defined by composition, scale and crosscutting relations. Thin (grey and black) layers located under and to the right of the pen, are defined by mafic layers alternating with relative plagioclase-rich layers, and are inferred to be relicts of igneous cumulate layering. In contrast, layers like the 20-cm-thick quartzofeldspathic layer to the left of the pen crosscut the thin layering, and are inferred to be metamorphic in origin.*

Plate 6. *Possible relict chill margins in metatonalite dyke (?) (centre of photograph) that intrudes Unit 3 metatonalite. The chill margins are preserved as fine-grained, light-grey layers.*

biotite, and in some cases, they are completely pseudomorphed by bastite. Some orthopyroxene grains have a thin corona of clinopyroxene.

On the basis of mineral composition and field relationships, the metatonalite is correlated with metatonalite farther north in the Ashuanipi Complex in NTS map area 23J. The U–Pb geochronological studies of metatonalite in the Ashuanipi Complex indicate igneous crystallization ages in the range from 2700 to 2680 Ma (Table 1).

GRANITOID GNEISS (UNIT 4)

Unit 4 is a heterogeneous division of mainly pink-, grey-

and white-weathering granitoid gneiss and migmatite. The unit also contains enclaves of metatonalite, which is lithologically similar to Unit 3, and biotite migmatite of uncertain affinity, but possibly equivalent to Unit 1. Contacts between the granitoid gneiss and the metasedimentary migmatite (Unit 1) are diffuse zones consisting of granitoid gneiss and abundant enclaves of the metasedimentary migmatite. The contacts are placed where the amount of granitoid gneiss exceeds that of metasedimentary migmatite.

The paleosome of the granitoid gneiss is a fine- to medium-grained granoblastic rock consisting of quartz, plagioclase, K-feldspar, orthopyroxene (<15 percent) and between 5 and 10 percent biotite. The orthopyroxene is mainly fine grained, but also occurs as medium-grained, elliptical-shaped orthopyroxene poikiloblasts that are texturally similar to the poikiloblasts in Units 1 and 3. Locally, orthopyroxene alters to hornblende and chlorite, and in some rocks it is completely pseudomorphed by bastite. The paleosome also contains accessory magnetite and apatite.

The unit contains less than 35 percent leucosome consisting of quartz, plagioclase, K-feldspar, and minor orthopyroxene. Commonly, outcrops contain two phases of leucosome distinguished on the basis of their crosscutting relationships. The older of the two phases forms thin, 1- to 2-cm, anastomosing layers that occur throughout the rocks. The younger phase is coarser grained, and typically forms 10- to 15-cm-thick layers. Both phases contain local orthopyroxene.

The gneisses in the southern part of the study area (i.e. south of Sawbill Lake; Map 97-04) contain more biotite than those in the north. Outcrops containing a relatively high percentage of biotite have a comparable composition and appearance to the metasedimentary migmatite unit, although they do not contain garnet or sillimanite. The gneisses in the southern part of the study area also lack abundant leucogranite intrusions, which make up a significant part of this unit in the northern part of the study area.

Variably deformed and recrystallized, white- to pink-weathering leucogranite intrusions occur as sheets (Plate 7) and small bodies throughout Unit 4, and locally make up 60 percent of the unit. Leucogranite sheets are up to 10 m thick. The intrusions are discordant to foliation and gneissosity in host gneisses, although the leucogranite is recrystallized and variably deformed. Locally, the leucogranite contains minor amounts (<5 percent) of biotite.

METAPYROXENITE (UNIT 5)

Metapyroxenite occurs in the northeastern part of the study area as dykes (or sills?) up to several hundred metres thick that intrude the metasedimentary migmatite (Unit 1),

Plate 7. *Leucogranite sheet (light-coloured rock along the top of the outcrop) that intrudes granitoid gneiss (Unit 4). The leucogranite is discordant to the gneissosity in the host gneiss but is itself recrystallized and weakly foliated suggesting that it is a late syn-metamorphic intrusion.*

metatonalite (Unit 3) and granitoid gneiss (Unit 4) units. Contacts between the metapyroxenite and the host rocks are sharp. Xenoliths of metapyroxenite, which are correlated with Unit 5 on the basis of lithology, occur within the diatexite (Unit 6).

Outcrops of metapyroxenite are massive to weakly foliated, and locally display a thin (1- to 2-cm) layering defined by the percentage of mafic minerals; the layering may be relict igneous layering. The rocks are black-, or black- and dark-green-weathering and are typically medium to coarse grained and have granoblastic textures. Most of the unit consists of olivine pyroxenite composed of variable amounts of clinopyroxene, orthopyroxene and olivine pseudomorphs. The rocks locally contain up to 50 percent olivine pseudomorphs consisting of serpentine and very fine-grained magnetite. Clinopyroxene is more abundant than orthopyroxene.

The unit also includes a minor amount of medium- to coarse-grained amphibolite consisting of 80 percent hornblende, clinopyroxene and minor biotite. The contact relations between the amphibolite and the olivine pyroxenite are undefined.

DIATEXITE (UNIT 6)

Unit 6 is the most abundant unit in the study area (and is subdivided into four subunits). It consists of coarse-grained, orthopyroxene-bearing igneous rocks that have compositions ranging between granodiorite and monzogranite; these rocks are known as diatexites as defined by Brown (1973). The four subunits are distinguished based on the presence or absence of garnet, and the abundance of gneissic inclusions. The subunits are: 6a – homogeneous diatexite containing ortho-

pyroxene and garnet, 6b – inhomogeneous diatexite containing orthopyroxene and garnet, 6c – homogeneous diatexite containing orthopyroxene, and 6d – inhomogeneous diatexite containing orthopyroxene (*see* Plates 8 to 13). Gneissic inclusions constitute up to 25 percent of the homogeneous diatexite, and from 25 percent to 50 percent of inhomogeneous diatexite. This subdivision follows a legend developed by Percival (1989) for Ashuanipi Complex rocks in NTS map area 23J. Inclusions of Units 1 to 5 occur within the diatexite, with metasedimentary migmatite (Unit 1) and metatonalite (Unit 3) inclusions being the most common. The U–Pb geochronological studies of zircons, from diatexite plutons in the Ashuanipi Complex, have yielded igneous crystallization ages in the range from 2685 to 2650 Ma (Table 1).

Plate 8. *Typical field aspects of homogeneous orthopyroxene-bearing diatexite (subunit 6c) containing orthopyroxene and biotite "blasts" (dark spots). The photograph also shows a small, cognate (?) inclusion of finer grained, foliated diatexite that is more mafic than the host.*

Contacts between the diatexite and the older units are gradational and marked by composite zones consisting of abundant diatexite and country-rock enclaves. The contact zones are up to several hundred metres wide. Intrusions of diatexite are discordant to the migmatitic structure in the country rocks and in the gneissic enclaves. This relationship indicates that Units 1 to 5 were deformed and attained peak granulite-facies conditions prior to diatexite intrusion. The contact relationships also demonstrate that the contact is intrusive as opposed to being a transitional zone of progressive, *in situ* migmatization of the surrounding rocks. The diatexite is intruded by variably deformed, pink- to white-weathering orthopyroxene-bearing pegmatite veins, and granitic dykes.

The amount of gneissic inclusions in Unit 6 is locally variable, hence the contacts between the homogeneous and inhomogeneous diatexite subunits (i.e., between 6a and b, and between 6c and d) are gradational, and are approximated on the map. The homogeneous and inhomogeneous diatexites are

Plate 9. *Intrusive contact between two phases of homogeneous garnet-bearing diatexite (subunit 6a) that are distinguished on the basis of grain size and percentage of biotite. The relative age relations between the two phases are uncertain. The photograph illustrates some of the local compositional and textural variations in the diatexite.*

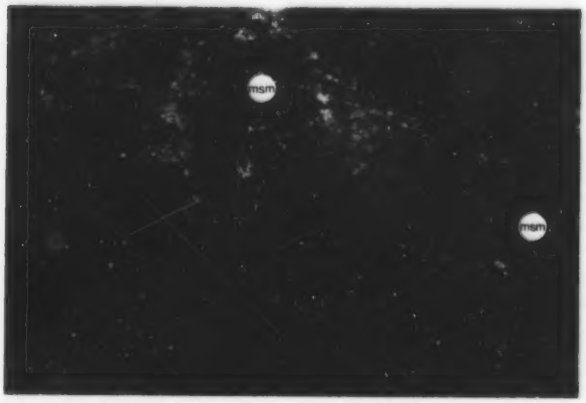

Plate 10. *Diffuse gneissic layering in homogeneous garnet-bearing diatexite (subunit 6a) defined by thin, biotite-rich lenses and coarser grained garnet – orthopyroxene granitoid rock. The outcrop contains a few, small inclusions of metasedimentary migmatite (msm) and thin, postmetamorphic pegmatites.*

not interpreted to be separate intrusive phases of the unit. Instead, the contacts mark an arbitrary boundary separating rocks that contain different amounts of inclusions.

Contacts between the garnet-bearing and garnet-absent diatexites are sharp and can be easily mapped. Contact relations are undefined, but the garnet-bearing and garnet-absent diatexites are considered to represent separate intrusive phases, based on the following observations. In the northern part of the study area, where garnet-bearing diatexite (subunit 6a) is common, garnet-absent diatexite (subunit 6c) occurs in small, discrete bodies within subunit 6a. In the central and southern parts of the study area these relationships are

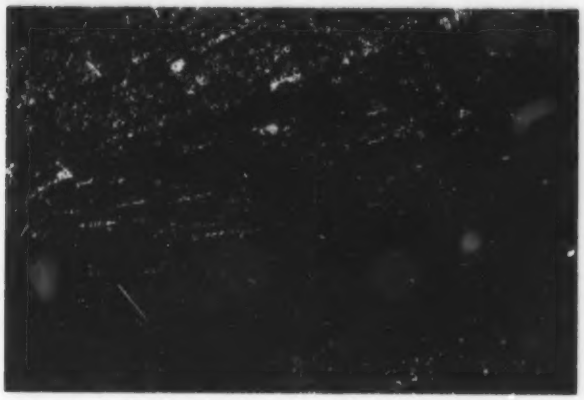

Plate 11. *Inclusion of metasedimentary migmatite in homogeneous garnet-bearing diatexite (subunit 6a). The inclusion contains orthopyroxene-bearing metamorphic leucosome that unequivocally predates emplacement of the diatexite.*

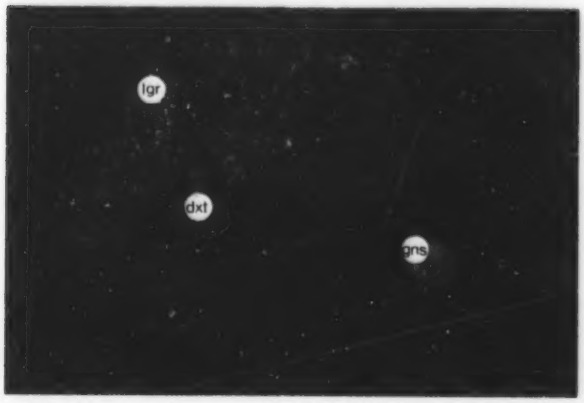

Plate 12. *Typical aspect of homogeneous diatexite (subunits 6a and c). The photograph shows diatexite (dxt) that surrounds a gneissic inclusion (gns) and is itself cut by a leucogranite dyke (lgr).*

Plate 13. *Outcrop of inhomogeneous orthopyroxene-bearing diatexite (subunit 6d) having a foliation ("pseudogneissosity") defined by flattened, elongate inclusions.*

reversed, suggesting that the garnet-bearing and garnet-absent diatexites are mutually intrusive.

Contained in each of the subunits is evidence for different intrusive phases of diatexite. For instance, homogeneous orthopyroxene diatexite (subunit 6c), containing inclusions, is commonly cut by a younger phase of homogeneous orthopyroxene diatexite that does not contain any inclusions. Different intrusive phases can also be distinguished on the basis of composition (e.g., differences in the amount of orthopyroxene) or texture. These minor variations cannot be represented.

The diatexite also has a varied texture and structure. Outcrops may consist of isotropic or foliated rocks, or they may have a migmatitic structure. Alternatively, they may have a "pseudogneissosity" defined by thin and highly attenuated inclusions. However, at the hand-specimen scale, the texture is relatively consistent. The rocks are mainly medium to coarse grained, and have a phaneritic (igneous) texture. Fine-grained, recrystallized (granoblastic) rocks occur only locally. Rocks containing coarse-grained K-feldspar phenocrysts, and medium- to coarse-grained, prismatic orthopyroxene grains are common. The rocks are white-weathering or have a maple-sugar bronze colour on the weathered surface.

The diatexite consists of variable amounts of K-feldspar, andesine, and quartz. Orthopyroxene and biotite are ubiquitous, and make up less than 15 percent of the rocks. They appear to be stable, based on their textures. However, in most rocks, orthopyroxene is variably altered to bastite, and locally, chlorite. Orthopyroxene retrogression is most extensive in areas south of Sawbill Lake. Garnet is texturally stable with biotite and orthopyroxene. It forms medium- to coarse-grained porphyroblasts and poikiloblasts containing abundant quartz and feldspar inclusions, and may make up to 15 percent of the rocks. The diatexite contains accessory magnetite, pyrite and zircon.

The intrusive relationship between the diatexite and the older units, and the fact that the diatexite unit contains inclusions having granulite-facies minerals and orthopyroxene-bearing-leucosome demonstrate the diatexite was not derived from *in situ* melting of the surrounding country rocks. However, geochemical studies by Percival (1991b) have shown the garnet-bearing diatexite to have a peraluminous composition, which is identical to the metasedimentary migmatite (Unit 1). The geochemical data and the intrusive field relationships suggest that complete melting of metasedimentary rocks in a structural level that was lower than the present erosion surface was the source of the garnet-bearing diatexite. Less amounts of melting of the same metasedimentary source, leaving residual garnet, may account for the garnet-absent diatexite (Percival, 1991b).

GRANITE (UNIT 7)

The area contains numerous but small bodies and dykes of late syn- to posttectonic, pink-weathering granite. Only a few of the bodies form mappable units. All granite occurrences interpreted to be late syn- to posttectonic intrusions are designated as Unit 7, although there could be several ages of granite included in this unit. Contacts between Unit 7 granite and the older units are sharp.

The unit consists of variably recrystallized, isotropic to weakly foliated syenogranite. The rocks are fine to medium grained, and have textures that range from phaneritic to granoblastic. The rocks contain microcline, less than 5 percent biotite, and accessory magnetite, apatite and epidote. The biotite is variably replaced by chlorite.

WALSH RIVER PLUTON (UNIT 8)

In the south (including NTS map areas 23G/3 and 23B/14), the area is mainly underlain by a composite pluton, the Walsh River pluton, which consists of white- and pink-weathering granite, and which is divided into three subunits, based on the composition, colour and inclusion content. The unit includes white biotite ± muscovite granite (subunit 8a), pink biotite granite (subunit 8b), and a heterogeneous subunit (subunit 8c) containing white and pink granite, granite gneiss and abundant inclusions of the older units. Subunits 8a and 8b are considered to be separate intrusive phases of the same pluton, although the contacts between the two phases are undefined. Contacts between the Walsh River pluton and surrounding, older units are sharp.

Subunit 8a is a white- to pink-weathering syenogranite to monzogranite. The rocks are mainly isotropic, although they are locally foliated. They are fine to coarse grained and contain microcline, pale green-weathering plagioclase, mauve quartz, minor biotite, and local muscovite. The feldspars are variably replaced by a very fine-grained mesh of white mica. The rocks contain accessory epidote.

Subunit 8b is a fine- to medium-grained, pink monzogranite containing biotite. The rocks are isotropic to foliated.

Subunit 8c is a heterogeneous unit that occurs in a very poorly exposed part of NTS map area 23B/14. It includes outcrops of white granite, probably equivalent to subunit 8a, and lesser amounts of granodiorite, tonalite, and pink-weathering granite. The pink granite contains abundant inclusions of granitoid gneiss, which are considered to be equivalent to Unit 4 on the basis of lithology. The granodiorite and tonalite are strongly recrystallized and somewhat gneissic, and may represent inclusions in the Walsh River pluton.

Field relations constrain the time of emplacement of the Walsh River pluton to be late syn- to posttectonic with respect to the high-grade metamorphism and deformation in the Ashuanipi Complex. The pluton displays the same field relationships with the older units as does the granite of Unit 7, suggesting that the two units are similar in age. Geochronological data from the pluton are lacking.

MAFIC DYKES

The study area contains three sets of mafic dykes that are distinguished on the basis of orientation. They include northeast- (050°), north-northwest- (345°) and east-striking dykes. They are not illustrated on the map because of their small size and limited extent.

The 050°-striking dykes and the 345°-striking dykes consist of fresh diabase. The rocks are fine to medium grained and contain lath-shaped plagioclase (≤2 mm), intergranular clinopyroxene, and accessory magnetite. There is some replacement of clinopyroxene by chlorite and amphibole, and of plagioclase by white mica. The igneous textures, isotropic structure and the fact that they are not deformed, demonstrate that they are posttectonic with respect to the Archean high-grade metamorphism and deformation in the host gneisses. On the basis of orientation, they may belong to the Paleoproterozoic Preissac (northeast) and Mistassini (north-northwest) dyke swarms, which occur elsewhere in the Superior Province (Fahrig and West, 1986).

In the Lac Virot area (NTS map area 23B/14), there are occurrences of approximately east-striking metagabbro dykes. The rocks are medium grained, foliated and weakly gneissic and the gneissosity is defined by thin (<2 cm) mafic layers. The dykes are cut by thin, pink-weathering granite veins. Rivers (1985a) has correlated these dykes with the ca. 1460 to 1420 Ma Shabogamo Gabbro, although they have not been radiometrically dated.

STRUCTURE AND METAMORPHISM

ARCHEAN STRUCTURE

A relative chronology of Archean intrusive, structural and metamorphic events has been established for the study area based on field relationships. These events are discussed here and summarized in Figure 6.

Local occurrences of compositional layering in paleosomes of the metasedimentary migmatite and metatonalite units are the oldest recognized structures in the study area. The layering, interpreted to be relict bedding and igneous layering, respectively, is completely transposed into the principal foliation (S_1) defined by the peak granulite-facies minerals, orthopyroxene and biotite. The principal foliation in the mafic gneiss, granitoid gneiss and metapyroxenite units is also defined by granulite-facies minerals, and is correlated with the S_1 fabric in the metasedimentary migmatite and metatonalite units.

The S_1 fabric in Units 1 to 5 is folded by tight to isoclinal folds designated as F_2 folds. In the northeast (Domain A, Figure 7), the F_2 folds are mainly northwest-trending with moderate to steep plunges. In the central part of the area (Domain B, Figure 7), the attitude of F_2 folds is highly varied because they have been reoriented by later folds also of inferred Archean age. In the south (Domain C, Figure 7), the F_2 folds are mainly west-northwest trending, and have shallow to moderate plunges.

The S_1 fabric and F_2 folds must predate the intrusion of the diatexite. This conclusion is based on the interpretation of the presence of inclusions in the diatexite that are correlated with Units 1 to 5 and contain the S_1 fabric and minor F_2 folds. The fact that the inclusions also contain the first phase of metamorphic leucosome indicates that the leucosome also predates the diatexite. The first-phase leucosome, which contains local orthopyroxene, is also deformed by F_2 folds and the formation of the leucosome is considered to be approximately coeval with the development of the S_1 fabric.

The metasedimentary migmatite commonly contains a second phase of leucosome that is discordant to both the first-phase leucosome and S_1 fabric, but contains the peak metamorphic assemblage. The relationships between F_2 folds and the second-phase leucosome are varied, although in some outcrops the second-phase leucosome clearly crosscuts F_2 folds (Plate 14).

The diatexite is heterogeneously strained, varying from isotropic to strongly foliated over several hundred metres. The variations in strain intensity can be best explained by local and regional heterogeneities in the distribution of strain, as opposed to a model that predicts different intrusive ages for rocks of different strain states. The foliation in the diatexite is defined by biotite, and by alignment of flattened and attenuated inclusions. Some rocks display a weak gneissosity defined by layers containing different amounts of biotite, and by layers of orthopyroxene-bearing leucosome.

The diatexite is intruded by numerous thin dykes of pink and white leucogranite. The dykes also intrude Units 1 to 5, and are particularly abundant in the granitoid gneiss (Unit 4). They are recrystallized and variably deformed although they postdate the fabric in the host diatexite.

The F_2 folds in Units 1 to 5, the foliation in the diatexite, and the aforementioned granite dykes are deformed by at least two sets of folds (F_3 and F_4), resulting in the formation of Type-I and modified Type-II (Ramsay, 1967) fold interference patterns. The pattern of superposed folds defines the map pattern of structural culminations and depressions. The culminations are cored by diatexite, and the depressions by metasedimentary migmatite, metatonalite and granitoid gneiss.

Two examples of map-scale Type-II patterns occur in the northern part of NTS map area 23G/14, where folded tonalite and diatexite define a Type-II mushroom-cap-shaped fold, and in the Milner Lake area, which contains a modified Type-II pattern defined by folded metasedimentary migmatite and granitoid gneiss. The Type-II and modified Type-II folds are inferred to have formed by refolding of reclined F_3 folds about west- to northwest-trending F_4 fold axes. An upright, dome-and-basin interference pattern (Type I), defined by diatexite, metasedimentary migmatite and granitoid gneiss, occurs in the northeastern part of NTS map area 23G/10.

The foliation in diatexite is folded by F_3 and F_4 folds and is principally reoriented by the F_4 folds into a west-striking attitude (Figure 8). This relationship, and the fact that the folds also deform the leucogranite dykes, suggest that the timing of the superposed folds is late syn- to postmetamorphic with respect to the granulite-facies metamorphism in the study area.

The Walsh River pluton is mainly isotropic and has a phaneritic texture. There are only local occurrences of foliation suggesting that intrusion of the pluton generally postdates the Archean deformation in the older units. The age of this foliation, which is defined by biotite, is uncertain; it could be a late tectonic Archean fabric, or it could be Grenvillian. There is also the possibility that rocks in the southern part of the Ashuanipi Complex could contain Labradorian (ca. 1720 to 1600 Ma) fabrics and structures. Geochronological data are necessary to test these models.

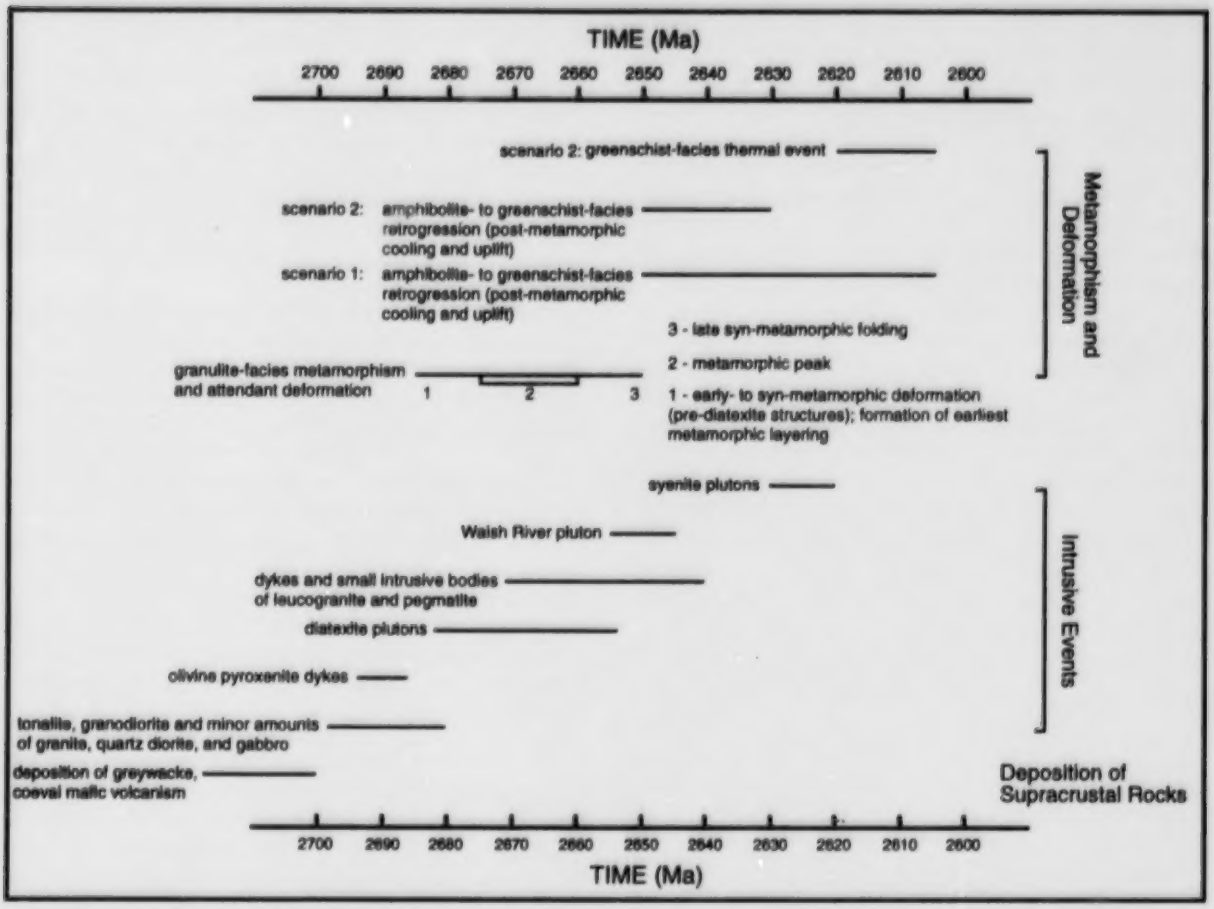
TIME (Ma)
2700 2690 2680 2670 2660 2650 2640 2630 2620 2610 2600
scenario 2: greenschist-facies thermal event
scenario 2: amphibolite- to greenschist-facies retrogression (post-metamorphic cooling and uplift)
scenario 1: amphibolite- to greenschist-facies retrogression (post-metamorphic cooling and uplift)
3 - late syn-metamorphic folding
2 - metamorphic peak
granulite-facies metamorphism and attendant deformation
1 2 3
1 - early- to syn-metamorphic deformation (pre-diatexite structures); formation of earliest metamorphic layering
Metamorphism and Deformation
syenite plutons
Walsh River pluton
dykes and small intrusive bodies of leucogranite and pegmatite
diatexite plutons
olivine pyroxenite dykes
tonalite, granodiorite and minor amounts of granite, quartz diorite, and gabbro
Intrusive Events
deposition of greywacke, coeval mafic volcanism
Deposition of Supracrustal Rocks
2700 2690 2680 2670 2660 2650 2640 2630 2620 2610 2600
TIME (Ma)

Figure 6. *Composite summary diagram showing timing relationships between depositional, intrusive, and tectonothermal events in the study area in the context of major events recognized in the eastern Ashuanipi Complex. Timing of events is constrained by geochronological data (Table 1) and by field relationships. The Walsh River pluton and the olivine pyroxenite dykes are undated and their ages are inferred entirely from field relationships. The diagram indicates two possible models for the post-granulite facies (2650 to 2600 Ma) thermal history of the Ashuanipi Complex. Model 1 suggests that rocks were progressively uplifted and cooled through amphibolite- to greenschist-facies conditions in the interval 2650 to 2600 Ma. Model 2 suggests that the rocks may have been uplifted and cooled through amphibolite- to greenschist-facies conditions in the interval 2650 to 2630 Ma, and subsequently overprinted by a 2620- to 2600-Ma thermal event represented by growth of new monazite.*

ARCHEAN METAMORPHISM

The metasedimentary migmatite contains the assemblages: a) biotite–orthopyroxene–K-feldspar, or b) biotite–orthopyroxene–garnet–K-feldspar, or c) biotite–garnet–sillimanite–K-feldspar. The orthopyroxene-bearing rocks are the most widespread, whereas there are only rare occurrences of sillimanite-bearing rocks. There are no occurrences of coexisting sillimanite and orthopyroxene. Both phases of leucosome in the metasedimentary migmatite contain orthopyroxene.

The mafic gneiss, metatonalite and granitoid gneiss units contain orthopyroxene in the paleosome and leucosome. In the mafic gneiss and metatonalite, orthopyroxene coexists with clinopyroxene, plagioclase, and commonly hornblende. The textural relations of orthopyroxene and hornblende are equivocal; in some rocks the two minerals appear to be texturally stable, whereas in other rocks, hornblende has grown around orthopyroxene grains. The latter relationship suggests that at least locally, hornblende is not part of the peak, equilibrium assemblage.

Orthopyroxene is also ubiquitous in the diatexite. Field relations demonstrate that emplacement of the diatexite postdated the formation of orthopyroxene in the paleosome and in the first-phase leucosome in the older units. This constrains the time of emplacement of the diatexite to approximately syn- to late syn-thermal peak.

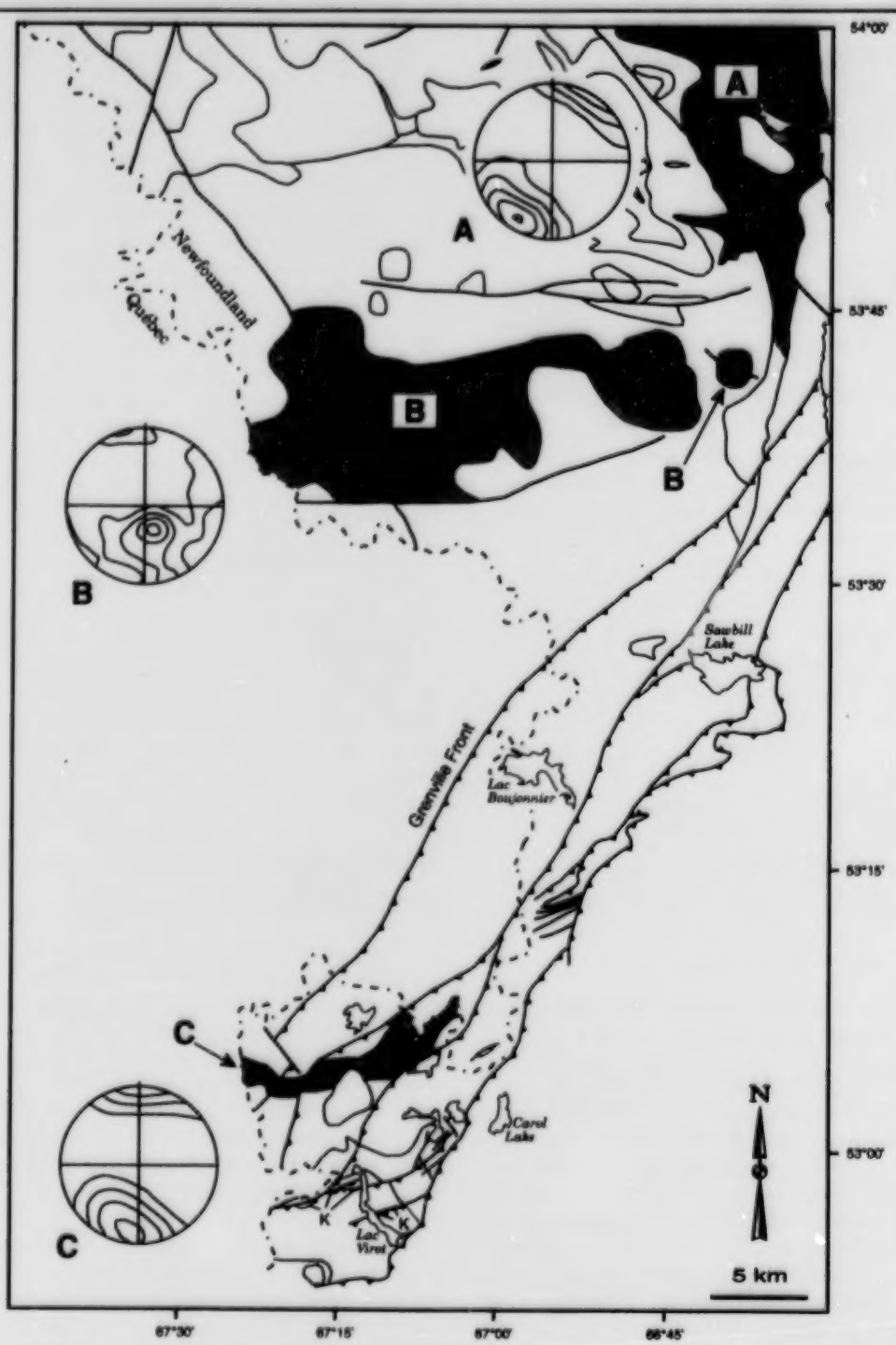

Figure 7. *Structural domains in the study area (see stippled areas). Contoured, lower hemisphere, equal area projection of poles to S_1 in Units 1 to 5. Domain A – n=68, σ=1.32; Domain B – n=98, σ=1.37; and Domain C – n=19, σ=1.02. Labels for map units are shown in Figure 5. Domain A is dominated by northwest-trending F_2 folds (pre-diatexite structures) that transpose the S_1 fabric. In Domain B, the S_1 fabric is deformed by superposed folds (post-diatexite structures) producing relatively flat-lying dome-and-basin structures. In Domain C, S_1, in Units 1 and 4, is folded by west-northwest-trending F_2 folds. K = Knob Lake Group.*

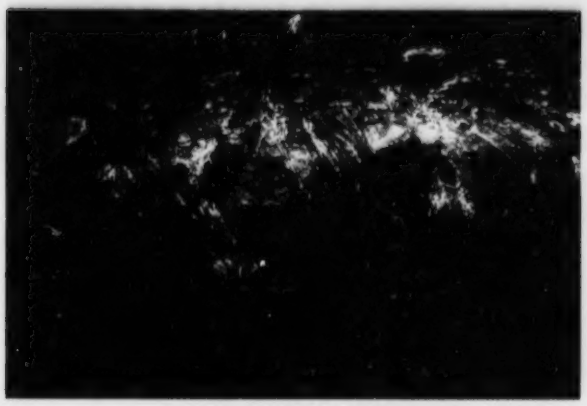

Plate 14. *Northwest-trending F_2 fold in metasedimentary migmatite that is defined by the biotite foliation (S_1) and the first phase of metamorphic leucosome. The fold is transected by lesser deformed second-phase leucosome that is also orthopyroxene-bearing.*

Figure 8. *Contoured, lower hemisphere, equal area projection of poles to foliation and gneissosity in diatexite (Unit 6); n=264, σ=1.45.*

The widespread occurrence of rocks containing orthopyroxene and biotite suggests peak metamorphic temperatures were in excess of 750°C (e.g., Grant, 1973). Coexistence of orthopyroxene and plagioclase, and the absence of coexisting orthopyroxene and sillimanite, or clinopyroxene and garnet suggest that equilibrium pressures were less than approximately 7 kbar (*see* Grant, 1973; and unpublished petrogenetic grids by D.M. Carmicheal and E. Froese). These conditions are consistent with the results of thermobarometric studies on orthopyroxene and garnet-bearing metasedimentary gneiss and diatexite from the adjacent NTS 23J map area, which indicate temperatures in the range from 750 to 850°C and pressures from 3.5 to 6.5 kbar (Percival, 1991b; Percival *et al.*, 1991).

In all rock types, orthopyroxene is variably pseudomorphed. It is commonly replaced by bastite, and less commonly by amphibole and chlorite. This replacement is inferred to be related to a greenschist-facies retrogression of Ashuanipi Complex rocks. The retrogression, although widespread, is most extensive in areas south of Sawbill Lake. Two models may explain the retrogression in this area. First, in rocks occurring near Grenvillian faults, the retrogression may be Grenvillian and related to hydration along the faults and the formation of Grenvillian minerals and structural fabric elements. Second, in rocks not having demonstrable Grenvillian fabrics and where pseudomorphing appears to be a static feature, the retrogression may be an Archean feature related to the late syn- to posttectonic intrusion of the Walsh River pluton. Granulite-facies rocks adjacent to this intrusion may have been rehydrated by fluids released from the crystallizing granite, thus enhancing retrogression of the surrounding country rocks.

In the north, greenschist-facies retrogression is inferred to be an Archean event related to rehydration during uplift. Here, the Archean age is favoured mainly because of the lack of demonstrable, penetrative Grenvillian fabrics. Also, the textures suggest that orthopyroxene replacement is principally a static feature. One potential source for rehydrating fluids, which may have initiated retrogression, are the numerous, late syn-metamorphic granitic dykes which occur throughout the area.

GRENVILLIAN STRUCTURE AND METAMORPHISM

The southern part of the study area contains several northeast-striking faults whose locations and extents are inferred mainly from topographic and aeromagnetic lineaments. Some faults can be traced from the Ashuanipi Complex into Paleoproterozoic rocks of the Knob Lake Group. Van Gool (1992) has interpreted these faults as steeply east-dipping Grenvillian reverse faults or overturned back-thrusts. However, some of the faults contain Knob Lake Group rocks in the hanging wall, suggesting that they may have a component of normal displacement.

The faults are part of a system of structures that make up a northwest-vergent foreland fold-and-thrust belt in the Grenville Province of western Labrador (Figure 9) and named the Gagnon terrane (Rivers *et al.*, 1989). The fold-and-thrust belt is developed in Knob Lake Group rocks, which form a cover sequence, and basement rocks of the Ashuanipi Complex. It consists of two thrust systems; an older, thin-skinned system principally involving the cover rocks, and a younger system of thrusts involving thick sheets of cover and base-

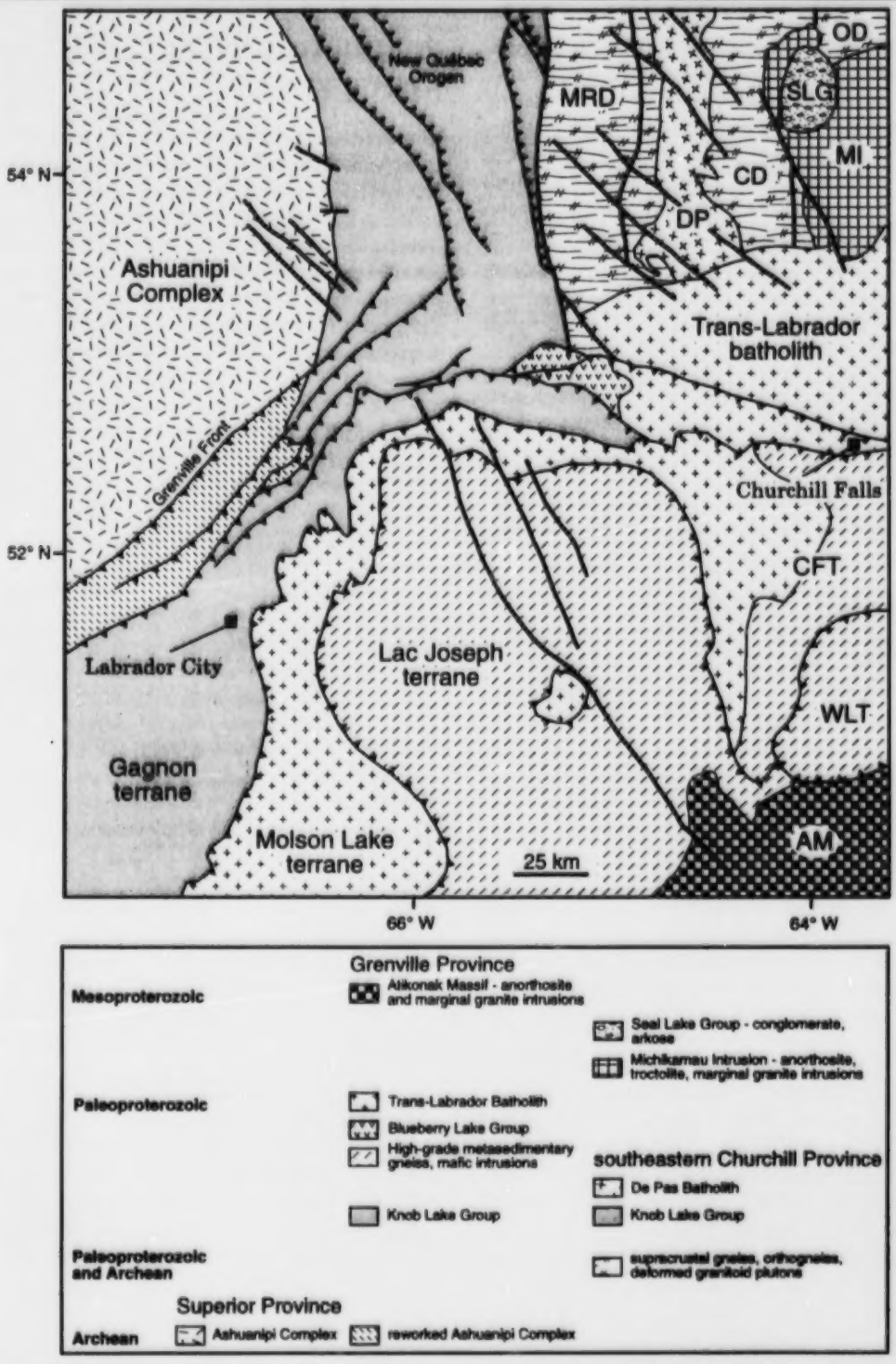

Figure 9. *Regional (Grenvillian) context of the study area. Shown are principal tectonic subdivisions of the Grenville Province in western Labrador, and adjacent southeastern Churchill Province (modified from James* et al., *1992, 1996). Grenville Province: CFT – Churchill Falls terrane, WLT – Wilson Lake terrane, AM – Atikonak Massif. Ashuanipi Complex rocks located southeast of the Grenville Front (see diagonal-hatch pattern) are considered part of the Grenvillian Gagnon terrane. Southeastern Churchill Province: MRD – McKenzie River domain, CD – Crossroads domain, OD – Orma domain, DP – De Pas batholith. Mesoproterozoic rocks: MI – Michikamau Intrusion, SLG – Seal Lake Group.*

ment (van Gool, 1992). The northeast-striking faults in the Ashuanipi Complex belong to the younger system of thrusts. Displacements on the northeast-striking faults are inferred to be minor. Some of the northeast-striking faults may be Paleoproterozoic normal faults that were reactivated during the Grenvillian, whereas others may be entirely Grenvillian structures (van Gool, 1992). The most northwestern of these faults defines the Grenville Front in western Labrador (James *et al.*, 1992).

Highly strained Ashuanipi Complex rocks along the northeast-striking faults are greenschist-facies quartzofeldspathic protomylonites and mylonites. The rocks contain the Grenvillian assemblage muscovite, biotite, carbonate and microcline, and lack evidence of the pre-existing Archean granulite-facies minerals. The Grenvillian assemblages in the high-strain zones are compatible with Grenvillian greenschist-facies assemblages in Knob Lake Group rocks, which occur as stratigraphic outliers and tectonic slices in the Ashuanipi Complex (Brown *et al.*, 1991; van Gool, 1992).

Grenvillian thermotectonic development of the Gagnon terrane is inferred to be in response to burial under a northwest-vergent thrust, which transported Grenvillian thrust sheets (Molson Lake terrane) over the Knob Lake Group and the southeastern margin of the Ashuanipi Complex.

OTHER GRENVILLIAN(?) STRUCTURES

In the northern part of the study area, the Ashuanipi Complex is deformed by several southeast- and east-striking faults. The faults are not exposed, although they are interpreted to deform the Archean–Proterozoic unconformity in the Menihek Lakes area based on offsets in aeromagnetic anomaly patterns. In addition, mapping by Percival (1989) in NTS map area 23J has shown that the same unconformity is deformed by east-striking faults. These faults must be younger than the Knob Lake Group, and could be Grenvillian structures.

The northern parts of NTS map areas 23G/14 and G/13, contain several north-northeast- to northeast-striking faults of uncertain age and kinematic history. The faults are not exposed and are inferred mainly from topographic and aeromagnetic lineaments. The regional importance of these structures is unclear.

ECONOMIC GEOLOGY

High-grade Archean supracrustal terranes have traditionally not been regarded as promising exploration targets for gold. However, regional geochemical and geological studies in the Ashuanipi Complex detected local anomalous concentrations of gold in lake-sediment and bedrock samples, and higher background levels of gold than would normally be expected from a high-grade supracrustal terrane (*see* Geological Survey of Canada, 1982a, b; Hornbrook and Friske, 1989; Thomas and Butler, 1987; Butler, 1987; McConnell *et al.*, 1987; McConnell and Newman, 1988). The geochemical results combined with documented occurrences of gold in the Ashuanipi Complex northwest of Schefferville, Quebec (Lapointe, 1986, 1989; Lapointe and Chown, 1993), and gold occurrences in similar Archean high-grade supracrustal terranes in Zimbabwe (e.g., Böhmke and Varndell, 1986) and Australia (e.g. Barnicoat *et al.*, 1991), suggest that Archean supracrustal rocks in the study area may have been favourable for gold mineralization.

Gold in the Ashuanipi Complex, northwest of Schefferville at Lac Lilois, occurs in metamorphosed iron formation, which is deformed by late syn- to postmetamorphic ductile shear zones (S.R. Chevé, personal communication, 1992). The iron formation is contained as a layer within metasedimentary migmatite and is located approximately 100 m from a tonalite intrusion. The gold mineralization is described in some detail by Lapointe and Chown (1993) who interpret the mineralization to share many of the characteristics of low- to medium-grade Archean mesothermal gold deposits, including: 1) enrichment of Au, As, S, Sb, W, U, and FeO, 2) depletion of Na and K, 3) low, base-metal/gold ratios, 4) proximity of gold mineralization to a granitoid intrusion, 5) an iron-enriched, fractured host rock, and 6) late syn-metamorphic mineralization.

Recent models for Archean mesothermal gold mineralization (e.g., Colvine, 1989; Fyon *et al.*, 1989; Cameron, 1989; Groves *et al.*, 1992) suggest the source of gold-mineralizing fluids is the lower crust and possibly the upper mantle, and that during crustal thickening and regional metamorphism, syn- to late syn-metamorphic $H_2O + CO_2$ fluids carry gold mineralization to the upper crust. In some circumstances, gold is deposited in deep crustal levels, probably because of favourable host-rock characteristics and focused fluid flow. In the Lac Lilois example, gold mineralizing fluids may have been focused along the sheared boundary between competent iron formation and relatively incompetent metasedimentary migmatite, and may have been influenced by local, granitoid intrusions (Lapointe and Chown, 1993). In addition, fluids may have been preferentially transported through the iron formation because it is coarser grained and more texturally heterogeneous at the grain scale than the finer-grained and texturally homogeneous, metasedimentary migmatite (Lapointe and Chown, 1993). The interaction between the mineralizing fluids and the iron formation may have caused precipitation of the gold (e.g., Groves *et al.*, 1992).

Significant occurrences of iron formation contained in the metasedimentary migmatite unit in the study area are unknown, although there are several occurrences of small (<1 m), pods and lenses of rusty, pyritiferous metasedimentary gneiss that may be the relicts of boudinaged silicate-sulphide facies iron formation. Several rusty pods were sampled and analyzed, but the concentration of gold did not exceed the lower detection limit of 5 ppb in any of the samples.

Lake-sediment geochemical anomalies of gold sympathetic elements (e.g., As, Hg, Cd, Cu, Pb, Mo, Ag, Zn and Co) in the study area (*see* Geological Survey of Canada, 1983a, b), led Thomas and Butler (1987) and McConnell *et al.* (1987) to do follow-up sampling of bedrock and boulder samples in areas surrounding the anomalies. None of the samples collected, including rocks from the metasedimentary migmatite, mafic supracrustal gneiss and diatexite units, contained significant amounts of gold. The highest gold values (20 ppb) came from a sample of metasedimentary migmatite from NTS map area 23G/15 (*see* Thomas and Butler, 1987, sample 52).

The metapyroxenite unit is a potential exploration target. In the study area, these rocks have not been closely examined or analyzed, although in areas to the north the unit includes rocks having relict igneous layering and cumulate textures (Percival and Girard, 1988). The composition of these rocks and the igneous structures suggest that the unit may have some potential for PGE or Ni–Cu mineralization.

DISCUSSION

Field relations demonstrate that the metasedimentary migmatite is the oldest unit in the study area. These rocks are inferred to be derived from greywacke on the basis of their mineralogy and the presence of relict bedding in the paleosome. This is consistent with geochemical data collected from Ashuanipi Complex metasedimentary rocks that demonstrates their bulk composition is typical of Archean greywacke (Percival, 1991b). The mafic gneisses interlayered with metasedimentary rocks are inferred to be derived from mafic volcanic rocks that were stratigraphically interlayered with the greywacke.

A model for the tectonic setting of deposition proposes that the supracrustal rocks were deposited in a sedimentary prism between accreting, Archean volcanic arcs (Percival and Williams, 1989; Williams, 1990). This model cannot be tested using data from the study area, because the scale of the model greatly exceeds the scale of the mapped area. The sedimentary prism that includes the Ashuanipi Complex rocks is thought to consist of the Ashuanipi, Opinaca River, Nemiscau River, Opatica and Quetico subprovinces, making up a metasedimentary-dominated belt having a strike length greater than 2100 km (Percival, 1990; Percival *et al.*, 1991).

The supracrustal rocks were intruded by several intrusive units prior to onset of a major, regional thermotectonic and magmatic event at approximately 2685 Ma (Mortensen and Percival, 1987; Percival *et al.*, 1991). The pre- to early metamorphic igneous units include plutons and smaller, related dykes of tonalite, diorite and gabbro, small plutons and dykes of biotite granite, olivine pyroxenite and diabase dykes. Field relations suggest that the tonalite and related diorite and gabbro are the oldest of the pre-metamorphic igneous units. On the basis of similarity in composition and field relations with the other units in the study area, the tonalite and related diorite and gabbro, and the olivine pyroxenite are correlated with Percival's (1991a) Desliens Igneous Suite.

On the basis of texture, Nagerl (1987) and Percival (1991a) proposed that orthopyroxene in the Desliens Igneous Suite tonalite is igneous in origin, and that the orthopyroxene poikiloblasts represent relict igneous orthopyroxene oikocrysts. The presence of igneous orthopyroxene may suggest that these rocks are analogues of dry calc-alkaline magmas intruded at medium to deep crustal levels in magmatic arcs along active Phanerozoic margins (Percival, 1991a). However, the interpretation of the orthopyroxene poikiloblasts as igneous is equivocal, based on the observation of very similar spongy-textured orthopyroxene poikiloblasts in metasedimentary migmatite in the study area; the orthopyroxene poikiloblasts in the metasedimentary rocks must be metamorphic. Nevertheless, the tonalite and the other pre-metamorphic igneous units in the study area might be related to calc-alkaline magmatism above a subduction zone in the narrow interval between 2700 and 2680 Ma. Termination of subduction at ca. 2685 Ma may have resulted from collision of the Ashuanipi sedimentary belt with a magmatic arc, possibly represented by either the Abitibi or La Grande River subprovinces, leading to the regional, high-grade tectonothermal event in this part of the Superior Province. Geochemical and geochronological data are required to test this model.

Inclusions of metasedimentary migmatite and tonalite contained in the diatexite demonstrate that pre-diatexite units (i.e., Units 1 to 5) were deformed and metamorphosed to granulite facies prior to diatexite emplacement. Metamorphic assemblages in pre-diatexite units indicate that the thermal peak was in the range from 750 to 850° C. Using chemical data, Percival (1991b) suggested that the garnet-bearing diatexite was derived from complete melting of the metasedimentary rocks at deeper crustal levels than are exposed in the study area (Figure 10). The source of the garnet-absent diatexite is less certain, but it could be derived by incomplete melting of the same metasedimentary source, leaving garnet in the residue (Percival, *op. cit.*).

Development of foliation in units that predate the diatexite is inferred to be approximately synchronous with the thermal peak of granulite-facies metamorphism. Diatexite emplacement is interpreted to be syn- to late syn-thermal peak. The diatexite and older units are deformed by at least two phases of late syn-metamorphic folds. The superposition of folds produced the regional-scale map pattern of structural culminations and depressions; the culminations being cored by diatexite, and the depressions by the older units. The youngest folds have reoriented the older structures producing the dominant west-northwest structural trend in the study area.

The Walsh River pluton is a composite intrusion consisting mainly of biotite ± muscovite leucogranite. Field relations and mineralogy suggest it is a late syn- to posttectonic peraluminous intrusion, although chemical and geochronological data are lacking. The absence of high-grade minerals and its low state of strain suggest it was emplaced into granulite-facies country rocks after the latter had been uplifted to moderate to shallow (?) crustal depths. A model relating intrusive and tectonothermal events in the study area (Figure 6), constrained by field relations and geochronological data, predicts that the Walsh River pluton was emplaced sometime between 2655 and 2645 Ma. An estimate for the maximum average uplift rate is 2 to 3 km/my, assuming 10 to 15 km of uplift over a 5 my period. Rapid, postmetamorphic

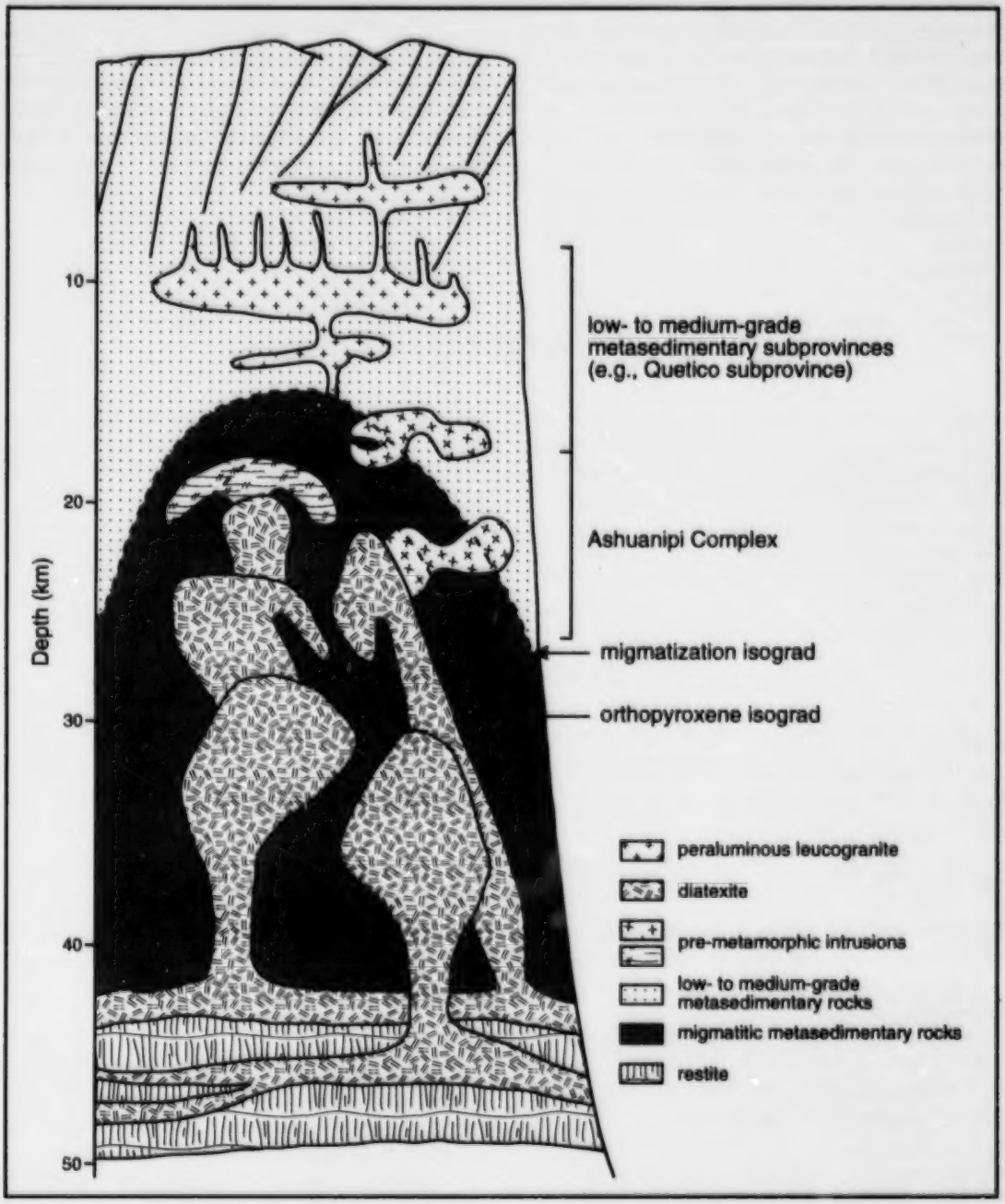

Figure 10. *Composite, schematic cross-section through a Superior Province metasedimentary belt (reproduced, with minor modifications, from Percival 1990, Figure 8). Shown is a section through the Ashuanipi "metasedimentary belt" in the approximate interval 2685 to 2650 Ma, and containing features compiled from lower grade areas to the west of the Ashuanipi Complex.*

(2665 to 2640 Ma) uplift of high-grade rocks in the Ashuanipi Complex is supported by U–Pb monazite ages (Percival, 1990). Geochronological studies of the Walsh River pluton and thermobarometry of minerals in the aureole around the intrusion are necessary to test this model.

Granulite-facies rocks in the south are extensively retrogressed to amphibolite and greenschist facies. The spatial relationship between areas of retrogression and the Walsh River pluton suggests that the retrogression may be a consequence of rehydration of the country rocks with fluids released from the crystallizing intrusion.

The southern part of the study area is overprinted by a Grenvillian thermotectonic event at ca. 1000 Ma (van Gool, 1992; Connelly and Heaman, 1993). Grenvillian structures include steep, east-dipping ductile shear zones that define reverse faults and overturned back thrusts (van Gool, 1992). Archean, granulite-facies assemblages are extensively retrogressed in these Grenvillian high-strain zones. Grenvillian deformation was attendant with greenschist-facies metamorphism.

High-grade Archean supracrustal terranes have traditionally not been regarded as favourable settings for gold mineralization. However, lake-sediment geochemical anomalies of gold sympathetic elements, background gold levels that are slightly higher than might be expected from a high-grade terrane, and gold occurrences in the Ashuanipi Complex northwest of Schefferville, Quebec, suggest that the Ashuanipi Complex has some exploration potential.

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